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GEOLOGY OF TEXAS PANHANDLE OIL AND GAS FIELD[1]

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ABSTRACT

Oil is found in formations along the flanks of an old buried granite ridge trending northwest and southeast. Gas is found in formations along and on the crest of this ridge. The beds are arched over the ridge as a result of compaction of sediments or diastrophic movements, or both. The shallow Permo-Pennsylvanian non-red beds are divided into five zones from bottom up: "granite wash," dolomitic arkose, coarse white dolomite, fine brown dolomite, and anhydrite. The first four are oil and gas reservoirs. Oil usually accumulates where the porous portions of these four zones intersect a plane slightly above sea-level. There is definite demarcation between the sweet and sour gas. This results from the gravitational separation of the heavy hydrogen sulphide into that portion of the gas situated low on the ridge. At the time of accumulation of oil and gas, the eastern end of the ridge was higher, generally, than the western, resulting in the greatest accumulation of sour gas in the northwest, while only sweet gas accumulated in the southeast. This condition also accounts for the heaviest oil being on the northwest. Subsequent tilting now gives the axis of the ridge a southeast plunge.

INTRODUCTION

The Texas Panhandle oil and gas field is probably the most extensive field in the world, having an area of more than 1,800 square miles and a length of about 120 miles. When the territory is completely developed it is probable that there will have been outlined

[1] Read before the Association at the Wichita meeting, March 23, 1935. Manuscript received, March 30, 1935.

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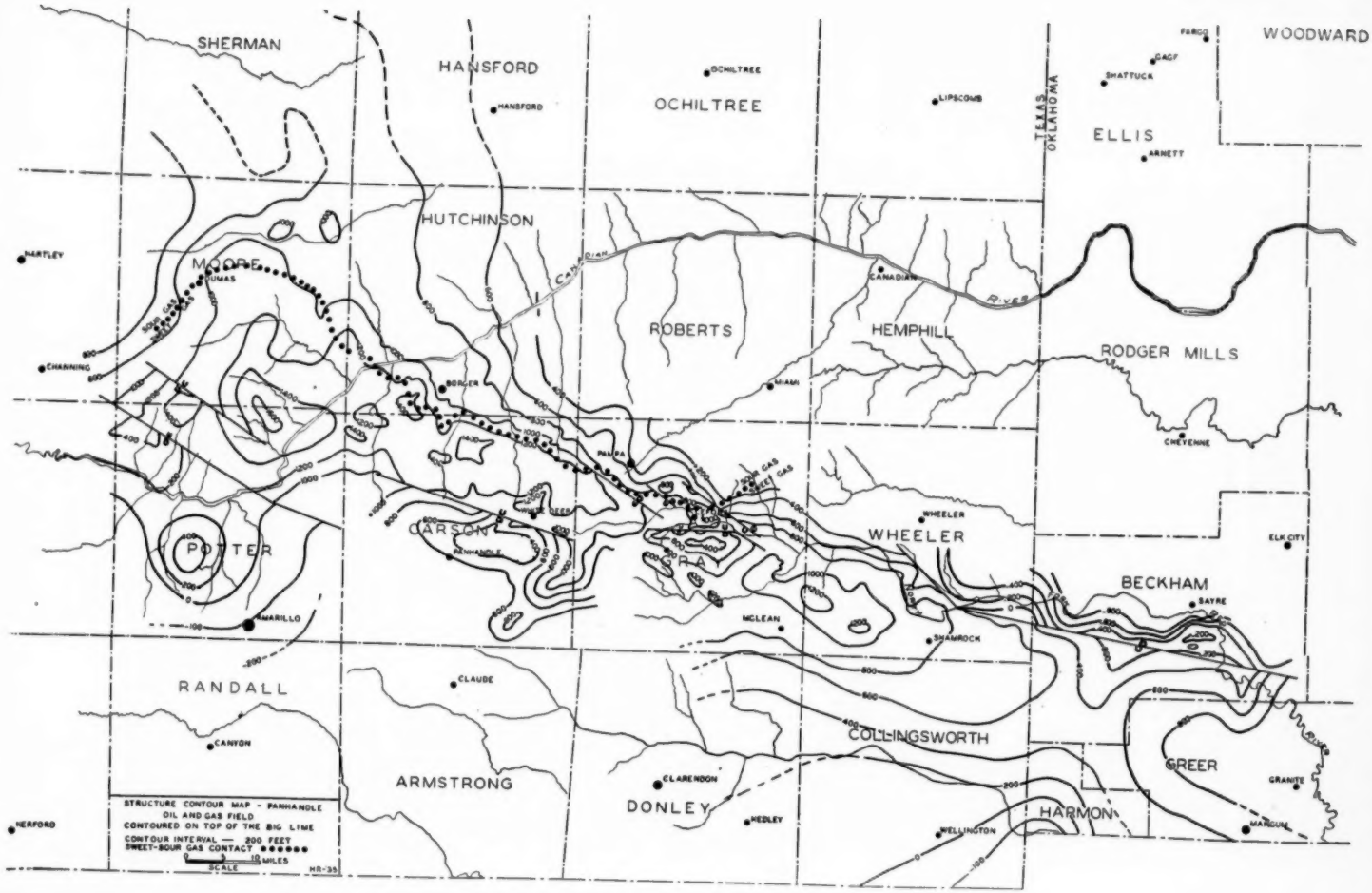

FIG. 1.—Structure map, Panhandle oil and gas field, contoured on top of "Big lime."

one continuous oil and gas field, and all of the pools, now seemingly separate, will have been found to be connected.

There have already been extracted from this field almost 250 million barrels of oil from about 3,250 wells. It is probable that at least 500 million barrels are still recoverable by present methods from the shallow producing formations in proved and potential areas. Artificial flooding and other methods of secondary recovery may increase the ultimate yield enormously. At present, the average daily production of the field is approximately 60,000 barrels. Almost 200 wells are now drilling.

This field is undoubtedly the largest continuous gas-producing area known. Although the active operations in this field have been carried on for only 10 years, it has been estimated that more than 3.5 trillion cubic feet of gas have already been removed. This estimate includes the gas used for light and fuel, carbon black, and that enormous amount which has been blown into the air. Estimates regarding the future recoverable gas range from 12 to 38 trillion cubic feet, a supply that will last 15–50 years at the present rate of production of 2 billion cubic feet a day.

As a normal result of the enormous gas reserve, many natural gasoline and carbon-black plants and long pipe lines have been built. The forty-nine natural gasoline plants have a capacity of approximately 2.25 billion cubic feet a day, and the 27 carbon plants burn daily almost half a billion cubic feet of gas. Furthermore, 9 interstate pipe lines carry 400 million cubic feet of gas every day to points as distant as St. Louis, Chicago, Fort Worth, and Denver.

RELATION OF SURFACE TO SUBSURFACE

The scope of this paper is confined largely to those counties forming the four northernmost tiers in the Texas Panhandle. The area is outlined in Figure 1, which shows the regional contours of the Amarillo Arch mapped on the top of the Panhandle "Big lime."

The greater part of the Texas Panhandle is a vast area of level plains. Where the water-sheds approach the broad meandering rivers, the monotony of this even-lying country is broken. Locally, there are wide areas of rolling gravel-topped hills; in many places where the Red-beds lie close to the surface, the country is dissected into a rugged mass of steep-sided hills and small peaks, typical of a country of readily eroded formations under arid or semi-arid climatic conditions.

In many places, the subsurface structures are reflected on the surface. The result of the first gas well drilled in this field is the best proof of this. Charles N. Gould located the well in northern Potter

FIG. 1.—Structure map, Panhandle oil and gas field, contoured on top of "Big lime."

County, on the John Ray dome, which he mapped from the exposures of the Alabaites dolomite. Subsequent drilling proved that this surface dome is a reflection of a subsurface "high." In many other places, there are suggestions of this surface reflection in the diversion of the courses of rivers or streams. The North Fork of the Red River in central Gray County is a typical example. Here, the river forms a bend around the Le Fors structure. In Wheeler County, the river parallels the strike of the strata. Also, the creek, which winds its way across the northern part of Moore County, is deflected twice because of the structures which block its path and which are not otherwise well shown on the surface.

STRATIGRAPHY

As limited space prevents detailed description of the stratigraphy, more attention is here given to the oil- and gas-bearing section, that is, the Permian strata below the Red-beds (Wichita-Albany series).

Figure 2 is a composite diagram of the type section constructed from examinations of cuttings from wells in north Carson and south Hutchinson counties, in and around the Borger pool. This is the section commonly encountered in drilling for shallow production; it does not include any of the formations penetrated in deep drilling.

The stratigraphic arrangement here described is modeled after that constructed by J. J. Maucini[3] early in the history of the development of the oil field. Changes have been made where subsequent drilling and more complete information proved necessary.

In general, the stratigraphic column is divided into three parts.

Pre-Red-beds	Upper	Permian Red-beds
	Middle	Panhandle "Big lime"
	Lower	Granite wash

The pre-Red-bed section is divided into five zones, from the top downward, as follows.

Zone	*Description*	*Thickness in Feet*
A	Anhydrite, gray shale and marl	450
B	Brown dolomite (probably primary in origin)	150
C	Characteristic coarse white pearly dolomite (secondary origin)	200±
D	Dolomite similar to that in *C* zone containing much arkose (calcareous in lower part)	0–800+
E	Pink granite wash (arkose)	0–900+

GRANITE CORE

The core of the buried ridge is coarse red granite uplifted by folding or faulting. The granite is like that which forms the core of the

[3] The section was constructed in 1925 when J. J. Maucini, assisted by the writer, was with the Marland Oil Company in the Panhandle. Later, as district geologist for the Phillips Petroleum Company, the writer made necessary changes as warranted by more complete sample information from subsequent drilling.

Nemeha ridge of Kansas, or which underlies large areas of western Texas and Oklahoma. Generally, it is composed of coarse red feldspars and colorless quartz, with a few accessory minerals. In places, diorite or diabase dikes cut the core. In some areas, especially on the east in Gray County, the ridge contains masses of diabase, or other rocks high in ferromagnesian minerals. Where this is the case, the wash from

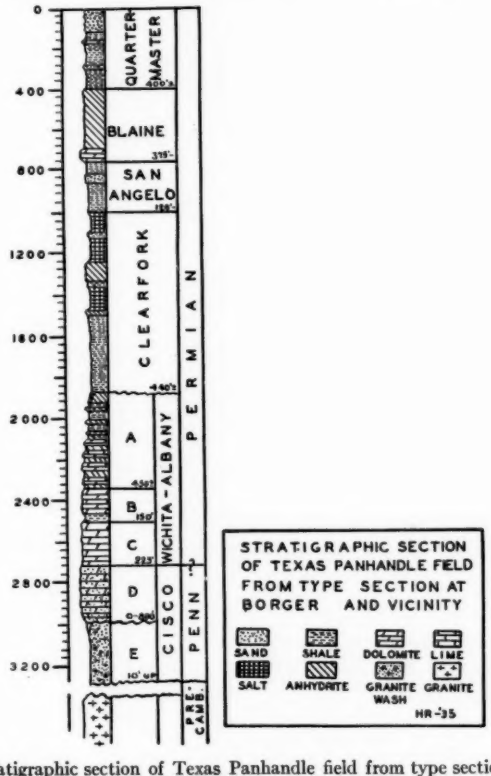

FIG. 2.—Stratigraphic section of Texas Panhandle field from type section at Borger and vicinity. Vertical scale in feet.

it is likely to produce high magnetic anomalies when worked by a magnetometer, and for this reason, care must be exercised in the interpretation of magnetometer surveys.

In general, very little is known about the nature of the granite core. Only a few widely separated wells have been drilled into it. Difficulty is often encountered in determining whether the formation

penetrated is solid granite or large boulders. A study of the relation between the granite and the Granite wash would be a great help to workers in the Panhandle.

E ZONE (GRANITE WASH)

The term "Granite wash" was the name given by the early drillers to the pink arkose, which is derived from the weathering of the granite core. Normally, the Granite wash consists of pink feldspars and colorless quartz.

The Granite wash is irregularly interbedded with coarse dark red hematitic shale, ordinarily forming lenses of Granite wash. However, in many places, generous amounts of Granite wash are scattered throughout the red shale. Also, red shale commonly acts as a cementing medium for the Granite wash. In general, though, the *E* zone can be best pictured as a series of interfingering red shales and clean Granite wash. It is important to visualize this condition since the irregularity of production is dependent upon the presence of these Granite-wash lenses and the amount of shale cement included. The location of the producing horizon with respect to sea-level is raised or lowered depending on the position of the shale cap in the section. The elevation of the producing zone above sea-level may vary from well to well. Finally, the presence or absence of these shales determines the method to be used in completing the wells.

The wash well up on the flanks or on top of the ridge lies directly on the solid granite from which it originated. Well down the flank, the wash lies unconformably on the truncated edges of pre-Pennsylvanian beds (Fig. 3). Individual fragments of the wash may vary in size from silt to large pebbles, and, in places, to very large boulders. Cores of these boulders have actually been obtained. The thickness of the wash ranges from zero to 2,800 feet or possibly more.

The *E* zone is considered as being equivalent to the Canyon-Cisco of north-central Texas.

D ZONE (ARKOSIC DOLOMITE)

The *D* zone immediately overlies a 10-foot bed of red shale which is the uppermost bed of the *E* zone. The *D* zone varies through most of its thickness from uncemented gray arkose to coarsely crystalline white dolomite including fragments of this arkose. The porosity of the formation is closely related to the amount of arkose present. The arkose, itself, consists of colorless quartz and gray feldspars (approximately labradorite in composition). The lower part of the *D* zone consists of soft white-to-buff "rotten" limestone of varying degrees of

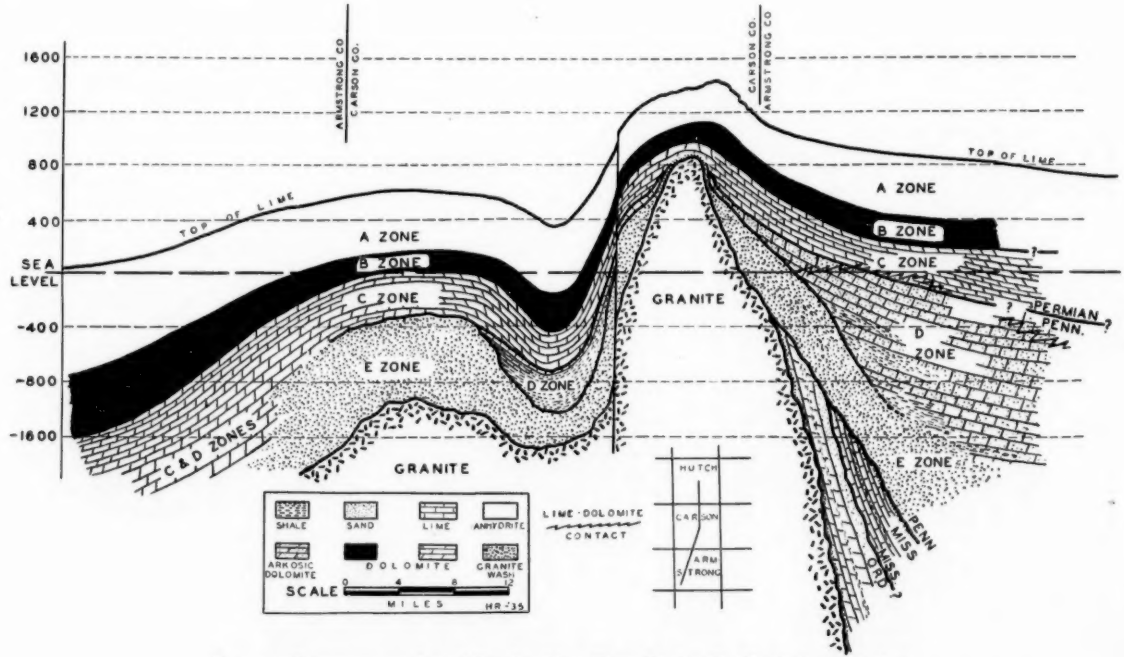

FIG. 3.—Transverse section of Granite ridge, Texas Panhandle. Vertical scale in feet. (Permian Red-beds not shown.)

porosity. Streaks of bentonitic (?) shale are common. The dolomite may grade laterally into less porous limestone. Accumulation in the calcareous portion of the *D* zone is very erratic and dry holes may offset large producers.

The *D* zone ranges in thickness from zero to 800 feet or possibly more. The thickness in the type section is 250 feet. The *D* zone is absent by non-deposition generally on top of the ridge and altogether on the south side of the ridge. In eastern Gray and western Wheeler counties, it is absent as low on the ridge as plus 800 "top of lime." In connection with the origin of the arkose, the absence or presence of the *D* zone becomes of great value in determining the geological history of the ridge, as is shown in the following paragraphs.

The *D* zone thins eastward along the strike as far as eastern Gray County where it is probably lacking, or it is represented by a bed only 10 or 20 feet thick. This bed, however, possibly lies in the *B* zone, and represents a reworked and redeposited portion of the *D* zone arkose, cemented with the material of *B* zone dolomite. There is no doubt that far enough basinward in this eastern area, the *D* zone is present in great thickness and of the character shown in its type section.

The source of the enormous mass of gray arkose presents an interesting problem. To the writer's knowledge, no solid rock has been encountered in the core of the ridge which would give rise to this material. Further, there is a very definite break between the underlying indigenous red Granite wash and the gray arkose. Although extensive research has not been completed, the writer believes he has found a satisfactory solution of the problem. He has good reason to believe that the arkose originated from the exposed groups of mountains in western Oklahoma. The most probable source seems to be the rock of the elevation called Raggerty Mountain, just west of the Wichita Mountains, which Taff[4] classifies as gabbro. Also in the Wichita Mountains Hoffman[5] classifies some of the rocks as gabbros and quartz gabbros. The predominating plagioclase in these rocks, as well as in the gray arkose, is labradorite.

According to the writer's theory, the debris from these mountains was carried into the Anadarko basin by continental streams. The longshore currents, directed by winds from the northeast, then carried the material northwest along the northern flank of the ridge.

[4] J. A. Taff, "Preliminary Report on the Geology of the Arbuckle and Wichita Mountains in Indian Territory and Oklahoma," *Oklahoma Geol. Survey Bull. 12* (1928), p. 57. Reprint of *U. S. Geol. Survey Prof. Paper 31* (1904).

[5] Malvin G. Hoffman, *Oklahoma Geol. Survey Bull. 52* (1930), p. 32.

Some of this material had to travel about 200 miles to its final resting place in Moore County. At this time, the ridge was slowly being submerged, and this arkose naturally accumulated in thicker deposits basinward, because of longer time of accumulation. Simultaneously with the arkose were deposited the limestones which later became dolomitized. Some evidence in favor of the origin and transportation of the arkose is the discovery of a fair thickness of the same material in a well in Kiowa County, Oklahoma, north of the gabbro outcrop already mentioned, and about 70 miles from the Texas State line, or the eastern end of the ridge.

C ZONE (WHITE DOLOMITE)

The dolomite of the *D* zone continues uninterruptedly into the *C* zone; the lithologic characteristics of the two dolomites are identical in the type section, except that the *C* zone dolomite grades upward into one of a light buff color and finer texture. The first appearance of the gray arkose marks the top of the *D* zone. There is no other basis for the division.

The top of the *C* zone is usually recognized by the appearance of buff dolomitic crinoids. The thickness of this zone ranges from 100 to 225 feet, although the average thickness is 150 feet. The upper 50–75 feet is composed of dolomitic oölites, which in some places are tightly cemented by colorless anhydrite. This portion of the zone is the well known producing horizon of the area west of Pampa and is referred to by the operators as the "Brown dolomite." However, it should not be confused with the real brown dolomite of the overlying *B* zone. This oölitic dolomite is part of the upper *C* zone and therefore belongs to the white dolomite series. Wherever properly located with reference to sea-level, and not too tightly cemented by anhydrite, this oölitic zone is almost universally productive of oil and gas in the Panhandle. In the eastern part of Gray County, the *C* zone is poorly represented. Probably erosion and lack of deposition are the causes.

Westward from Borger into Moore County, the *C* zone grades into soft white or buff "rotten" limestone, and thickens considerably and consistently. The porosity of the *C* zone dolomite is a result of recrystallization of the originally deposited calcium carbonate.

B ZONE (BROWN DOLOMITE)

The *B* zone overlies the *C* zone and is 150 feet of massive fine sugary buff dolomite with numerous chert nodules. The upper 10–20 feet of this massive dolomite is a very extensive bed of fine crystalline shaly buff dolomite which can not be distinguished from the underly-

ing dolomite in wells located on the crest of the ridge. Basinward, however, a wedge of white crystalline anhydrite separates this upper bed from the main body of dolomite. Throughout the Panhandle, this wedge ranges from zero to 100 feet in thickness. Lack of space prevents a more detailed discussion of its thickness in various places except to note that it thickens basinward, and about 10 miles north of the axis of the ridge the wedge attains a thickness of 60–80 feet. Twenty miles north of the ridge the *A*–*B* zones contact can not be placed because the upper dolomite bed becomes too indefinite or is entirely lost. The anhydrite wedge is not an addition to the *B* zone, but instead, it replaces the dolomite by gradation, thickening at the expense of the latter, so that the top of the *B* zone is placed at the top of the upper extensive bed of dolomite, which is 150 feet above the *C* zone.

The main body of *B*-zone dolomite underlying the anhydrite wedge is known in the Panhandle oil fields as the "brown massive dolomite" and is a very important marker for the operators. Some workers in the Panhandle believe this massive dolomite is the top of the *B* zone as described by the writer. This is true only where the anhydrite wedge is absent, which occurs, ordinarily, very high on the ridge.

Although the top of the "brown massive dolomite" is used as a marker for mapping by these workers, obviously this will not give a true regional picture, because of the gradational relation between the anhydrite wedge and the underlying dolomite. The top of the "brown massive dolomite" should be used for correlation locally, only.

A ZONE (ANHYDRITE)

The *A* zone immediately overlies the *B* zone, and in turn is overlain by the Permian Red-beds. This zone is composed largely of white and gray crystalline anhydrite, with interbedded gray shale and dolomitic shales. No oil or gas other than a questionable showing is ever found in it. However, it is valuable for correlative purposes. Correlation can be greatly aided by a microscopic examination of the *A* zone for the zone can be divided into an upper and a lower part which have distinctive lithologic characteristics and here and there oölitic horizons make good local marker beds.

"TOP OF LIME"

The top of the *A* zone is erroneously called the "top of the lime," since the early drillers thought the anhydrite was limestone. The comparative ease with which the "top of lime" can be determined in

driller's logs makes it the most used marker for mapping the subsurface structures. It has been noted in all wells drilled in the Panhandle and western Oklahoma, except in a very few drilled on peaks on the ridge crest, which were apparently emergent during all the time the anhydrite (*A* zone) was being deposited. The one great drawback in using the top of the *A* zone ("top of lime") for mapping is the common belief that it is an unconformable surface of rather wide areal extent. In places, this is no doubt true. But the real importance of this unconformity is a matter of great doubt, since the thickness of the *A* zone seems to be about 450 feet in most places. Erosion of this zone before the deposition of the overlying Red-beds seems to have been very slight, except in Moore County, where as much as 100 feet or more have been removed in some places. On the top of the ridge, in places, the full thickness of the *A* zone is not present, because of non-deposition and slight erosion.

SUBSURFACE STRUCTURES

GRANITE RIDGE

The Amarillo granite ridge forms the major subsurface structural feature of the Panhandle. For a long time, the ridge was considered to be the buried extension of the Wichita Mountains, but recent investigations tend to show that the two ridges do not have a common axis and that the Wichita Mountains seem to have a more northerly trend than the Amarillo ridge.

The Amarillo buried granite ridge trends northwest and southeast for a distance of at least 110 miles, extending from the central part of Moore County, southeast to the Oklahoma-Texas State boundary line. Because so few wells have penetrated into the granite core, little is known about the type or manner of formation of the ridge. However, the evidence available suggests that the ridge is an uplifted fault block with associated grabens or down-dropped fault blocks. These conditions are shown on the map.

FAULTING

Where faulting has occurred it seems to have been in *en échelon* arrangement (a series of offset faults) rather than one extensive fault. As a rule, faulting seems to have followed along original lines of weakness in the granitic basement. This faulting was progressive, continuing throughout the entire period of deposition of sediments. A good example of this is the Carson County fault shown in Figure 4. The displacement of the beds by the faulting becomes less and less higher in the section.

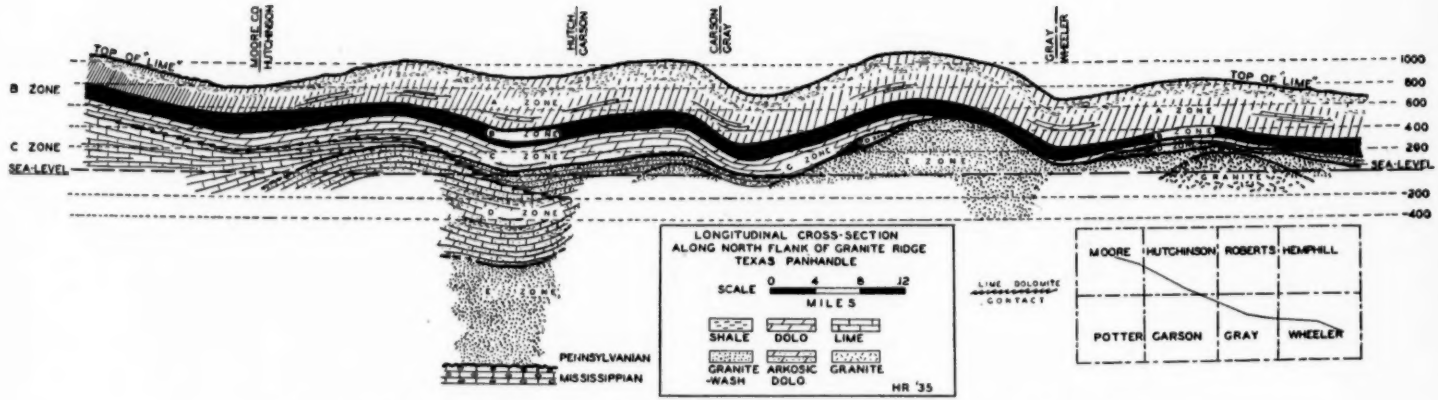

FIG. 4.—Longitudinal section along north flank of Granite ridge, Texas Panhandle. Vertical scale in feet. (Permian Red-beds not shown.)

Faulting ordinarily controls the extent of oil production only as it brings the porous productive horizons either above or below sea-level.

GEOLOGICAL HISTORY

Very little of the early geological history of the Panhandle is readable because of the lack of well cuttings which can be definitely referred to the pre-Pennsylvanian Paleozoic rocks. Two wells have certainly penetrated this early Paleozoic series: the Phillips Wilson 2 in northeast Moore County, and the Phillips Elva 12 in the Borger pool, just north of the town of Borger. Ordovician cherts and dolomites have been recognized in a few wells in Wheeler County, but in some places, these dolomites and cherts are probably detrital Arbuckle dolomite reworked into higher formations. Many of the fragments in question contain a tarry substance, resembling weathered oil-saturated dolomite. The Cambro-Ordovician seas certainly covered the Texas Panhandle, which probably was comparatively level—a peneplaned surface—with no near-by land masses. This series is represented by thick massive dolomites overlain by series of green shales and large etched sand grains.

No evidence of the Silurian and Devonian rocks has been found and the entire area was probably emergent during these periods. If the Silurian-Devonian beds were deposited, it is reasonable to expect some residue in the low areas, at least. Since rocks of these ages are absent from the area so far explored, it is reasonable to believe that these beds had not been deposited, rather than that erosion had removed them.

The sea once more advanced in early Mississippian time and remained until the close of that period, depositing at least 1,000 feet of limestones. The lower 200 feet contain much chert and may be equivalent to the Boone formation. The upper 800 feet is more probably of Chester age. This correlation is based largely upon similarity of lithologic character between this series and the known Chester in other areas and also on the position of the beds in the stratigraphic column.

At the close of the Mississippian, uplifting of great magnitude occurred, resulting in the quick deposition of at least a 300-foot series of detrital red and green shales and detrital limestones. The Pennsylvanian seas were now encroaching, depositing a thick series of black shales overlain by interbedded black limestones and black shales, closely resembling the Marble Falls series of north-central Texas, and probably of that age.

A further uplift took place which definitely brought into obvious

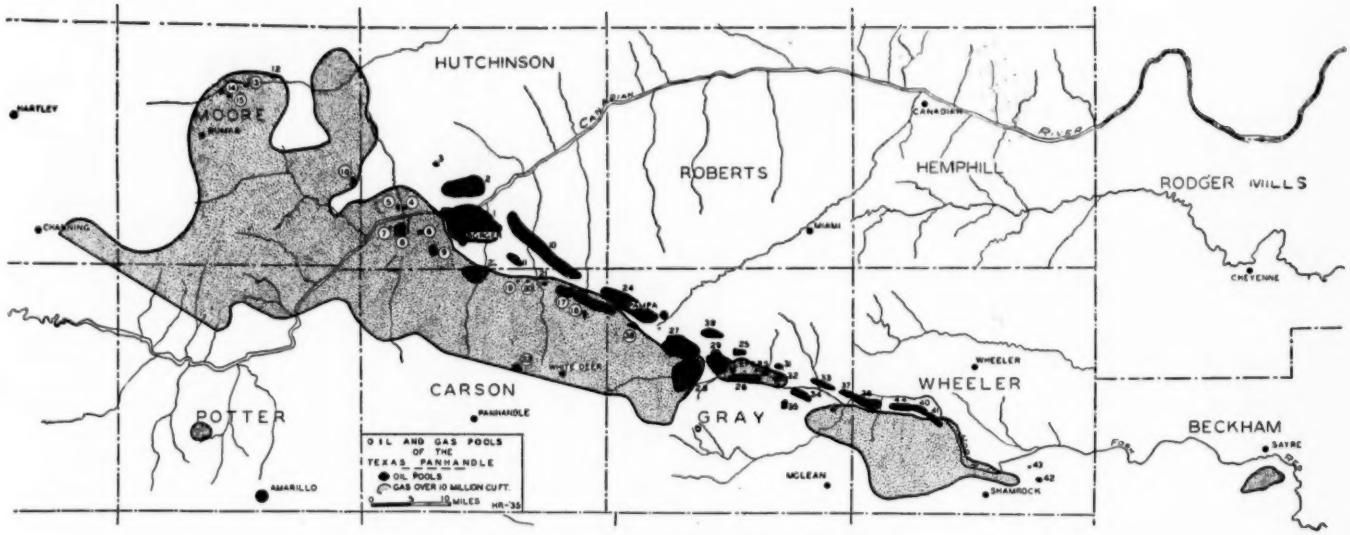

FIG. 5.—Oil and gas pools of Texas Panhandle.

Hutchinson County. 1—Borger. 2—Dial. 3—Stinnett. 4—Yake. 5—Merchant. 6—Sanford. 7—Bivins. 8—Trigg. 9—Margaret Johnson. 10—Moore-Watkins-Cooper. 11—McIlroy.

Moore County. 12—Sunray. 13—Morton. 14—Coffee. 15—Brumley. 16—Armstrong.

Carson County. 17—Roxana. 18—Noel-Schafer. 19—West Jordan. 20—Lewis. 21—Jordan. 22—Fields. 23—Burnett.

Gray County. 24—West Pampa. 25—Short. 26—Williams-Davis. 27—South Pampa. 28—Bowers. 29—Palmer-Combs Worley. 30—Eustis (Texas Saunders). 31—Key. 32—McLarty. 33—Morse. 34—Chapman. 35—Clayton-Chapman. 36—Vulcan. 37—Webb. 38—Latham.

Wheeler County. 38—D'Spain. 40—Bently. 41—Comprary. 42—Mankins. 43—Triangle well. 44—Koons.

existence the granite ridge, as shown by the Granite wash deposits. Since no Granite wash has been discovered in the section prior to this time, it is assumed that the granite core had not yet been exposed. This second uplift or recession of the sea was necessary before it was possible for the beds covering the granite to be completely eroded, thereby exposing the granite. The period of uplift is post-Bendian and pre-Ciscoan, possibly Strawn. The Granite wash deposit may have been formed during the entire interval between Bend and Canyon time. The late Pennsylvanian seas began to advance, and in the Anadarko and the Palo Duro basin (basin south of ridge), thick limestone deposits were laid down.

The beginning of *D*-zone time (end of Cisco) witnessed the further advance of the sea, so that only the higher parts of the ridge were emergent, forming a sort of archipelago. Some gabbro peaks in western Oklahoma were elevated well above sea-level. The Amarillo ridge was higher in the eastern end than in the western, which is exactly the reverse of the present relative positions of the ridge extremities. Only the crest of the ridge was above water, and that was undergoing gradual submergence. The gap between the ridge and the mountains of western Oklahoma was probably at, or just above, sea-level. This made it possible for the arkoses previously mentioned to be carried by littoral currents from Oklahoma into the Panhandle.

By the beginning of the *C*-zone time (beginning of Wichita-Albany), only a few peaks remained as islands. The ridge, and probably the whole region, began to tilt east or southeast. Both the tilting and advancing of the seas continued until the last of the *A* zone was deposited (end of Wichita-Albany). By this time, the western end was higher than the eastern and was possibly emergent. Erosion removed part of the *A* zone, the "top of the lime." The short period of erosion was succeeded by the deposition of the thick series of mostly continental Red-beds which were probably derived from areas on both the east and the west.

OIL AND GAS

SWEET AND SOUR GAS

The peculiar distribution of the sweet and the sour gas in this field is interesting. The gas is divided into two distinct zones: sweet and sour. A fairly distinct line marks the separation of these two. The sour gas contains various percentages of hydrogen sulphide, ranging from 2 to 500 grains per 100 cubic feet. It is a very significant fact that the sourest gas is located farthest west and low on the structure. The gas east of Le Fors is entirely sweet, as well as the gas located high on the ridge.

Gases of widely different densities in contact with each other diffuse very rapidly, but since these two gases have remained separated it seems that some physical conditions are reacting against this diffusion. The writer explains the peculiar distribution as being the result of gravitational separation. The hydrogen sulphide is twice as heavy as the sweet gas alone. The gases are prevented from diffusing because of the pressure exerted within the reservoir, since the molecular activity of a gas is greatly decreased under pressure. The diffusion of the sweet and sour gases is made even more difficult, because of the necessity of moving through fine pores in the rock, difficult enough under atmospheric pressure, and still more difficult under 28 atmospheres (420 pounds is the initial rock pressure of the field).

As previously stated, the examination of the lower "Big lime" section indicates that the deepest part of the basin, during the accumulation of oil and gas, was located in the area now included in northern Moore and Sherman counties. Eastward, the ridge became higher and higher, reaching an elevation sufficient in eastern Gray and western Wheeler counties to be emergent. Naturally, then, the heavier sulphur gas came to rest and remained in the western and deepest part of the basin, that is, Moore and Hutchinson counties. The area in Wheeler County was apparently high enough above the remainder of the ridge to allow only light or sweet gas to settle there.

If gravitation had separated the gases when the ridge was higher in the east, it is only logical to have expected a readjustment of the location of the sweet and the sour gas after tilting, placing the sour gas in the east. The only apparent answer to this is that the extensive connate water body, which seems to be connected with a more recent water body having a hydrostatic head, has entrapped and held in their original geographical and structural relationships, the oil and sweet and sour gas. This seems to have happened locally also where a pocket of sweet gas is occasionally entrapped in the sour gas zone.

OIL AND GAS HORIZONS

The productive horizons have been touched upon lightly in a description of the stratigraphy. Only a further brief statement can be made in this paper. One important point to remember is that oil is usually found where the position of the porous formations ranges from 110 feet above sea-level to nearly sea-level. There are, however, exceptional occurrences.

The relation between the oil horizon and sea-level is accidental and seems to have no geological significance other than that it is the plane at which the gas pressure and the hydrostatic head are equal-

ized, the gas forcing the oil down the structure and the hydrostatic head forcing the oil up the structure. If the gas pressure were to be decreased, the oil horizon would be forced upward by the hydrostatic head. The writer expects this condition to occur in the Borger pool, where the gas pressure has decreased from 420 pounds to less than 200 pounds. There is no doubt that this decrease in pressure will eventually (if it has not already begun) result in the migration and diffusion of the oil up the structure and into the overlying gas horizons. This would decrease the initial production and ultimate yield from each of the wells drilled in the future.

E ZONE

The *E* zone contained a large percentage of the oil and gas produced in the Panhandle. In Gray County, where it is best developed, it is also most productive. Ordinarily, the productive parts of the Granite wash are very irregular and spotted, as a result of interfingering red shale beds. These shales add greatly to production problems, and cause the mudding off and ruining of many wells. Wells drilled in these areas, in particular, must have technical care when being brought in. The writer is personally aware of many potentially prolific wells which, when completed, produced only 100 barrels or less a day—wells which should have produced 1,000 barrels or more. Frequently, these red-shale and Granite-wash mixtures slack immediately in contact with water, resulting in mudding-off of the producing horizon. So sensitive to moisture is this material, that when exposed to the air, even for a short time, the shaly wash begins to crumble. Proper knowledge regarding the drilling of this material is essential.

It is interesting to note that the productive zones of the Granite wash cut across the strike of the structure contours; for example, in Carson County the wash is productive at a "top of lime" of 1,100 feet and higher. Eastward, it gradually becomes productive lower and lower until, in western Wheeler County, favorable locations are found as low as the 700-foot contour. This is clearly shown in Figure 3. There is no fixed position in the wash zone at which oil may occur; in places, it is at the top; in others it may be 500 feet or more below the top.

The Granite wash is the one good exception to the rule about production occurring at or above sea-level, for in many places (Bower's pool, Gray County, for example) it produces at horizons 100 feet or more below sea-level. A possible explanation for this is that the oil originally accumulated at the present horizon, being held

in place by overlying interfingering shales which acted as a trap. Subsequently, the ridge tilted, so that the Granite-wash oil horizons were lowered and now the oil is found below sea-level. Entrapment of the interfingering red shales prevents migration of the oil up the flank of the structure. Normally, though, even the Granite-wash zone conforms to the rule.

The *E* zone contains most of the large wells (some with initial productions of 10,000–15,000 barrels). It is also a large gas reservoir.

D ZONE

The *D* zone, or gray arkose, is probably next to the least important of all the producing horizons. In many places, it is very thin, only about 10–20 feet; in many more places, it is missing. The best development is found in shallow wells in southern Hutchinson County, as a result of the elevating of the ridge toward the west, which placed a thicker section of the arkose in a position to be cut by the plane of sea-level. The Roxana pool, Carson County, is an example of *D*-zone production.

In most *D*-zone pools, the arkose is cemented by recrystallized dolomite. However, in western Hutchinson County in the Sanford pool, and in the northern part of the South Pampa pool, limestone is present instead of dolomite, so that the producing formation is a sandy limestone. The areas where the cementing materials are calcium carbonate are not as productive, being notably spotted and irregular. Dry holes are likely to offset good producers.

C ZONE

The most prolific *C*-zone area is the famous Borger pool, which covers an uninterrupted area of about 10 sections, or 6,400 acres. The southern part of this pool produces from the lower part of the zone where the dolomite is the coarse white crystalline variety—with large cavities as a result of recrystallization from limestones. The northern part of the pool produces from the upper part of the *C* zone, which consists of the medium-to-fine crystalline buff dolomite.

As already mentioned, the extensive area west of Pampa and continuing into Carson County and southeast Hutchinson County produces from the top part of the *C* zone, that is, the oölitic beds. Leases which will produce from this horizon are particularly sought by the oil companies and operators because of the steadiness of production. Once the flush is off, the production remains steady. One edge well had an initial production of 35 barrels a day. Since its completion in August, 1928, the well has produced 35,000 barrels and is now making

its allowable of 20 barrels a day. The average initial production of wells producing from this horizon is about 250 barrels a day.

Extending westward from Borger, the lower part of the dolomite grades into the unaltered limestone, and in places is productive in a spotty manner. This may be a result of faulting. However, the lack of good samples makes exact mapping of this area difficult. The new pool in northern Moore County, known as the Sunray pool, produces from the limestone, which may be either *C* or *D* zone, extended.

B ZONE

The *B* zone is least important as an oil producer; it is more important as a gas reservoir. Only in eastern Gray County and a narrow strip along the northern border of the dolomite area, is oil found in this zone.

SOURCE AND ACCUMULATION OF OIL AND GAS

The source of the oil and gas is of great concern. On it are based largely the possibilities for pre-Pennsylvanian oil. There are recognized two possible sources: (1) from Permo-Pennsylvanian beds, (2) from pre-Pennsylvanian, probably Ordovician rocks.

As far as the writer is concerned, the facts received from the investigation so far carried on do not favor one theory more than the other.

Significant, but certainly not conclusive, are the following facts favoring Permo-Pennsylvanian age: (1) the oil and gas are found exclusively in Permo-Pennsylvanian formations. In one well in Wheeler County, there is a possibility that production is from the Arbuckle. However, the cuttings suggest that this material may be reworked, and therefore more probably of Pennsylvanian age, (2) well out into the Anadarko basin are thick deposits of black carbonaceous shales and shaly limestones, which are equivalent in age to the *C*, *D*, and *E* zones (Permo-Pennsylvanian).

In favor of the pre-Pennsylvanian theory are these facts: (1) deposits of pre-Pennsylvanian age (Arbuckle to Chester) lap up onto the ridge and dip very steeply into the basin (Fig. 4). Everywhere along the crest and well down the flank of the ridge, these beds have been worn away. The truncated edges are capped by the Pennsylvanian deposits. This would have made it possible for any oil in the other beds to have migrated into the less steeply dipping Pennsylvanian formations, since the Granite wash would form a poor seal for any oil-bearing formation. (2) The Ordovician beds present contain oil in other fields where properly situated structurally.

NEW SHALLOW-PRODUCTION POSSIBILITIES

There still remain many areas in the Panhandle which present possibilities of future production.

1. Foremost among these is the extensive unexplored area of Moore County. There has been but little exploration for oil in this county. There are areas between wells sufficiently extensive to permit the location of pools twice the size of the prolific Borger pool. Production in Moore County will ordinarily occur well up on the structure. Therefore, one must make locations where the *C*-zone dolomite is situated sufficiently well up on the structure.

2. Southern Gray County (south of the *axis* of the ridge) presents an extensive area in which oil production may be reasonably expected. However, in this area, the pools, if found, will probably be of limited extent. In locating wells, care must be exercised to insure against drilling over granite peaks. The granite in this area is generally close to the surface, in contrast to the granite north of, or on top of, the ridge. The tops of these peaks are ordinarily 300–400 feet above sea-level. Since southern Gray County consists of numerous small granite peaks with accompanying small basins filled with Granite wash, it is not unreasonable to expect to find some good pools.

3. Another interesting prospective area is eastern Wheeler County, particularly the area north of the Remo pool.

POSSIBILITIES FOR DEEP PRODUCTION

Deep production in this field would mean pre-Pennsylvanian oil. The most discouraging argument against the possibility for deep production is the truncation of the pre-Pennsylvanian beds, cutting them away and well into the core of the ridge. For this reason, some geologists might be inclined to favor the idea that if any early Paleozoic oil had ever been present, it is now accumulated in the overlying or later Paleozoic reservoirs. This is a logical enough conclusion to those who know how porous are the Granite wash and other formations which cap the truncated beds.

The writer, however, favors the possibility of the entrapment of oil in these early beds, on structures which have a reversal of dip toward the ridge. These structures are present along the north flank of the ridge, and it is practically a certainty that they are covered by proper pre-Pennsylvanian beds. There are at least seven structures which comply with these conditions and which are logical places to test for pre-Pennsylvanian (probably Ordovician) oil, with chances for success.

The problem then resolves itself into this: if the oil accumulated

in the pre-Pennsylvanian beds before the uplift and truncation, it is probable that these beds will be barren of oil now; and that this oil is now in the overlying Permo-Pennsylvanian rocks. If, on the other hand, the oil accumulation occurred after the truncation of those early rocks, there is a good chance for the discovery of oil on structures sufficiently distant from the ridge.

WELL CUTTINGS

The writer desires to stress the value of collecting good well cuttings in this and other fields. The information gathered herein was based entirely on these cuttings. Almost unlimited information can be available to the operator, if he will only coöperate by insisting upon the collecting of good and complete sets of well cuttings by his drillers.

A good example of the value of samples is the uncertainty created among operators in the Sunray pool in northern Moore County, as already mentioned. Although twelve wells have been drilled here, with varying success, not one complete set of cuttings has been saved. The writer has had difficulty in locating a sample of the producing formation.

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VOL. 19, NO. 8 (AUGUST, 1935), PP. 1110-1130, 8 FIGS.

RÉSUMÉ OF ST. PETER STRATIGRAPHY[1]

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ABSTRACT

Fossils in the St. Peter sandstone series are valueless for exact stratigraphic determinations. In Minnesota and in the Ozark region, the beds overlying the St. Peter series were formerly correlated with the Stones River group, but are now known to be Black River in age. In both regions, strata of Beekmantown age underlie the St. Peter series. In the east, the Black River and Chazyan groups are present, but the St. Peter series is absent. In these three type outcrop regions, there is no evidence to support the generally accepted belief that the St. Peter-Buffalo River sandstone series is pre-Chazyan in age.

In the Arbuckle Mountains, Oklahoma, the Simpson group crops out as a thick series of formations which range from lower Chazyan to middle Mohawkian in age. Sediments entirely similar to the St. Peter series are present in the outcrops of this group and underground in Oklahoma. Chaos and controversies now rule Simpson stratigraphy.

When the surface beds have been mapped and studied in as great detail, and by the same stratigraphers using the same microscopic methods, as now applied to the samples of Ordovician rocks penetrated by wells drilled for petroleum, detailed and accurate correlations can be made between the surface strata and the buried rocks connecting separated outcrops; then, and only then, can the presence or absence and (if present) the stratigraphic position and exact age of the St. Peter series be determined and established.

Work to the present time indicates that when such studies have been completed the St. Peter series will be found in Oklahoma beneath beds of known Black River age, just as it occurs in the Upper Mississippi Valley, and above beds of known Chazyan age.

INTRODUCTION

The term "St. Peter" was first used to designate a formation in Minnesota consisting of thick friable sandstone overlain by limestone.[3] Later, the limestone was eliminated from the terminology

[1] Read before the Association at the Wichita meeting, March 21, 1935. Manuscript received, May 1, 1935.

[2] Research stratigrapher, Shell Petroleum Corporation.

This paper is a brief résumé of a much longer paper presented before the Geological Society of America, December, 1934, to which grateful acknowledgment is made for permission to publish this paper. The writer wishes to acknowledge the courtesy of the executives of the Shell Petroleum Corporation for permission to publish at this time some of the results of her scientific work during the past 10 years, and to express her appreciation to A. I. Levorsen, J. V. Howell, A. W. Giles, and H. S. McQueen for helpful criticism of the manuscript.

[3] J. N. Nicollet, "Report Intended to Illustrate a Map of the Hydrographical Basin of the Upper Mississippi River," *20th Cong., 2d. Sess., Senate Doc. 237* (Washington, 1843), pp. 1–170, quoted by N. H. Winchell and E. O. Ulrich, "Historical Sketch in Geology of Minnesota," *Minnesota Geol. and Nat. Hist. Survey*, Vol. III, Pt. 1 (1885–1892), p. xix.

and the term St. Peter was applied to the sandstone only. This St. Peter sandstone was recognized as a widespread, blanket sandstone in the Upper Mississippi Valley states of Minnesota, Iowa, Wisconsin, and northern Illinois. The meaning of the term was enlarged in 1911 to include beds both above and below the sandstone in the Ozark region; here the group composed of the Joachim, St. Peter, and Everton formations was called the St. Peter series, and, synonymously, the Big Buffalo and the Buffalo River series.[4] Later still, it was suggested that the Jasper formation probably belonged in the same group of sediments,[5] and in the present paper the terms St. Peter and Buffalo River series are used as inclusive of the Jasper formation. In those areas where the upper Everton member is absent and the St. Peter and Everton sandstones are in direct contact with one another, the term St. Peter sandstone has been applied to the combined sandstone unit.[6]

UPPER MISSISSIPPI VALLEY

As first used by Nicollet in 1843,[7] the term St. Peter was applied to "the geological formation St. Peters," which crops out at Fort Snelling and St. Anthony Falls, Minnesota, and "continues to show itself in the river of the same name," that is, St. Peter's River, renamed and now called Minnesota River.[8] "The type locality is at Fort Snelling, and the type section is that at the bluff where the Minnesota River joins the Mississippi River."[9]

The St. Peter sandstone is, in general, almost barren of fossils. Although several have been found in Minnesota and described by Sardeson,[10] they are very poorly preserved and so many of them are new species that exact correlations are not possible;[11] many of them are said[12] to be remarkably like those in the overlying limestone. As

[4] E. O. Ulrich, "Revision of the Paleozoic Systems," *Bull. Geol. Soc. America*, Vol. 22 (1911).

[5] A. H. Purdue and H. D. Miser, "Eureka Springs-Harrison, Arkansas-Missouri," *U. S. Geol. Survey Atlas Folio 202* (1916), p. 5.

[6] C. L. Dake, "The Problem of the St. Peter Sandstone," *Univ. Missouri School Mines and Met. Bull.*, Vol. 6, No. 1 (August, 1921), p. 21.

[7] *Op. cit.*, 3.

[8] N. H. Winchell and E. O. Ulrich, *op cit.*, footnote, p. xix.

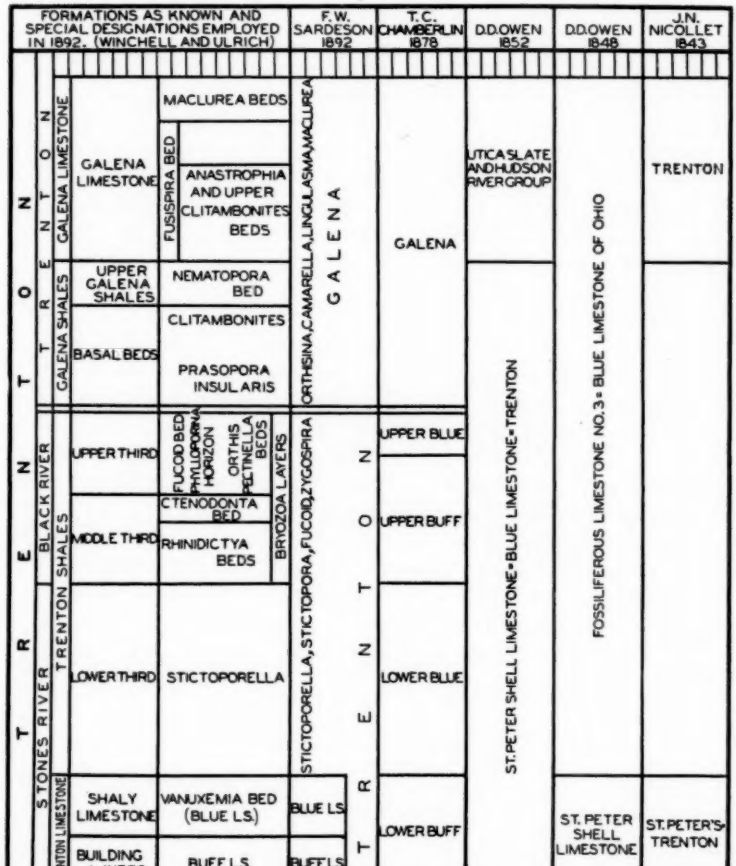
[9] C. R. Stauffer, "Type Paleozoic Sections in the Minnesota Valley," *Jour. Geol.* Vol. 42, No. 4 (May–June, 1934), p. 352.

[10] F. W. Sardeson, *Minnesota Acad. Sci. Bull. 4* (1892–1910), pp. 64–87.

[11] C. L. Dake, *op. cit.*, pp. 99–100.

[12] N. H. Winchell and E. O. Ulrich, "The Geology of Minnesota," *Minnesota Geol. and Nat. Hist. Survey*, Vol. III, Pt. 2 (1897), pp. xci–xcii.

Part of the "Table of Stratigraphic Designations Applied to the Lower Silurian in the Upper Mississippi Valley since 1823" is reproduced below.



N.H. WINCHELL AND E.O. ULRICH: *Geol. and Nat. Hist. Survey of Minn. Vol. III, Pt. I, pp. l-li*

FIG. 1

Summary of Correlations up to 1934, of beds above St. Peter Sandstone in Upper Mississippi Valley

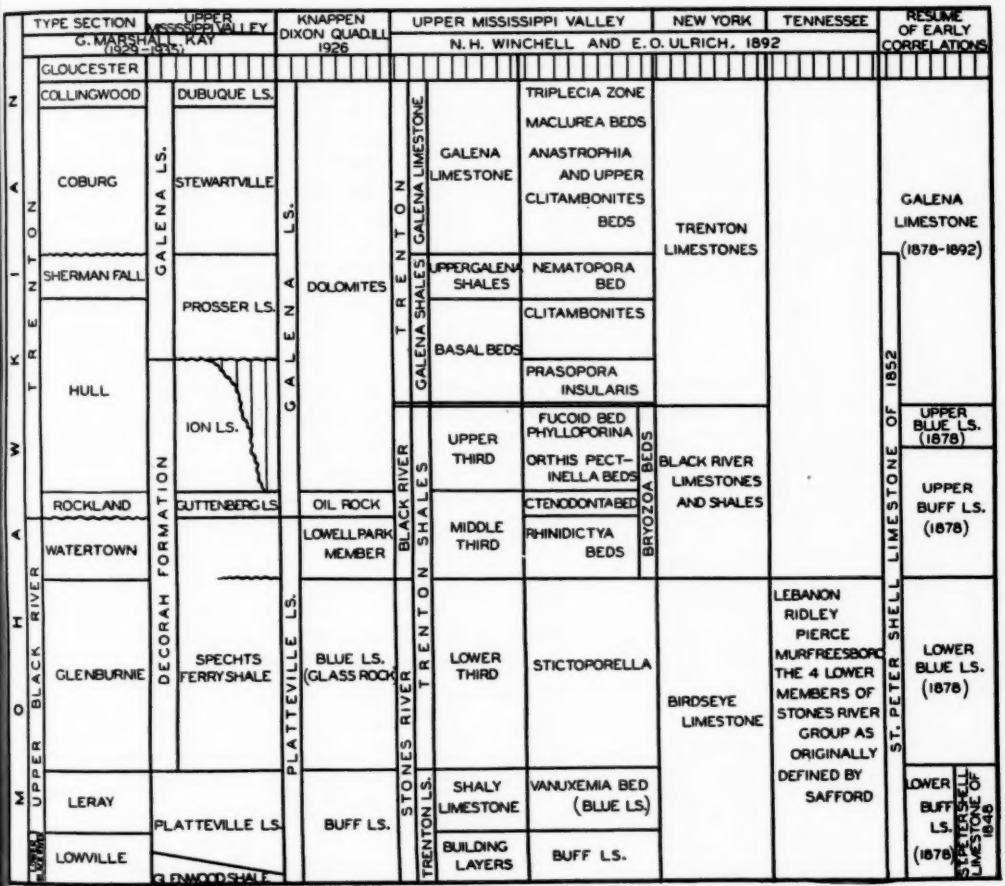


FIG. 2

it is evident that the age of the St. Peter sandstone at its type locality can not be determined by its fossils, the correct determination of its age and stratigraphic position is dependent on the correct interpretation of the beds overlying and underlying the St. Peter sandstone.

In "The Geology of Minnesota," Winchell and Ulrich[13] considered the "Lower Buff" and "Lower Blue" limestones overlying the St. Peter sandstone in the Upper Mississippi Valley to be Stones River in age, and correlated them with the Birdseye limestone of New York and with the four lower members of the Stones River group as originally defined by Safford in Tennessee.

The term "Galena limestone" is first found in the report by Foster and Whitney.[14] Bain, in 1905, named the limestone that overlies the St. Peter sandstone in the lead and zinc district in the contiguous corners of Wisconsin, Iowa, and Illinois, the Platteville limestone.[15]

In 1906 Calvin named and described the Glenwood shale in extreme northeastern Iowa,[16] where it directly overlies the St. Peter sandstone and underlies the Platteville limestone. In the same publication, Calvin gave the name Decorah to "the persistent body of shale between the two parts of what generally has been called the 'Trenton limestone.' "[17] Kay, in 1929,[18] raised the term Decorah to formation rank and defined three members of the Decorah formation, in ascending order: Spechts Ferry, Guttenberg, and Ion.

The work done subsequent to that of Winchell and Ulrich in the Upper Mississippi Valley has shown that the beds which there overlie the St. Peter sandstone are all Black River and Trenton in age. Stauffer's last statement, on the Glenwood shale, is that ". . . the fossil-bearing Glenwood beds belong in the Mohawkian series, and are not much older than the Platteville limestone."[19]

A correlation of Stauffer's, Branson's, and Mehl's work on the conodonts of the Glenwood, Joachim, and Harding formations, shown in Figure 3, is based on the following quotations.

[13] N. H. Winchell and E. O. Ulrich, *op. cit.*, p. xc.

[14] J. W. Foster and J. D. Whitney, "Report on the Geology of the Lake Superior Land District," Pt. II, "The Iron Region," *U. S. 32d Cong. Spec. Sess. 3, Exec. Doc. 4* (1851), p. 146.

[15] H. Foster Bain, "Zinc and Lead Deposits of Northwestern Illinois," *U. S. Geol. Surv. Bull. 246* (1905), p. 18.

[16] Samuel Calvin, "Geology of Winneshiek County," *Iowa Geol. Survey Ann. Rept.* (1905), Vol. 16, pp. 74–76.

[17] Samuel Calvin, *op. cit.*, p. 61.

[18] G. Marshall Kay, "Stratigraphy of the Decorah Formation," *Jour. Geol.*, Vol. 37, No. 7 (October–November, 1929), p. 644, also Fig. 8, p. 657.

[19] C. R. Stauffer, "Conodonts of the Glenwood Beds," *Bull. Geol. Soc. America*. Vol. 46, No. 1 (1935), pp. 129–31.

Stauffer, Branson, and Mehl Correlations for Glenwood-Joachim Formations

COLORADO	MISSISSIPPI VALLEY	MISSOURI	MINNESOTA
FREMONT	MAQUOKETA	CASON	MAQUOKETA
	GALENA	KIMMSWICK	GALENA
	DECORAH	DECORAH	DECORAH
	PLATTEVILLE	PLATTIN	PLATTEVILLE
		UPPER JOACHIM	GLENWOOD
HARDING	ST. PETER	LOWER JOACHIM	ST. PETER
		ST. PETER	
MANITOU	SHAKOPEE	JEFFERSON CITY (Undifferentiated)	SHAKOPEE

MOHAWKIAN

FIG. 3

Stauffer:

The Harding Sandstone of Colorado has been correlated with the St. Peter Sandstone of the Mississippi Valley.[20]

Branson:

The correlation of the Harding with the Joachim is based entirely on conodonts.[21]

Stauffer:

The conodonts of the Glenwood are closely related to those of the Platteville and Decorah on one hand and to those of the Harding sandstone on the other.[22]

The four lower members of the Stones River group as originally defined were the Central, Pierce, Ridley, and Glade limestones[23] (Fig. 4).

[20] C. R. Stauffer, *op. cit.*, p. 129.

[21] E. B. Branson and M. G. Mehl, "Conodont Studies No. 1," *Univ. Missour Studies*, Vol. 8 (1933), p. 20.

[22] C. R. Stauffer, *op. cit.*, p. 129.

[23] R. S. Bassler, "The Stratigraphy of the Central Basin of Tennessee," *Tennessee Dept. Educ. Div. Geol. Bull. 38* (1932), correlation chart in pocket.

Summary of Correlations Up to 1934, Ontario, New York, Kentucky, Tennessee, Minnesota

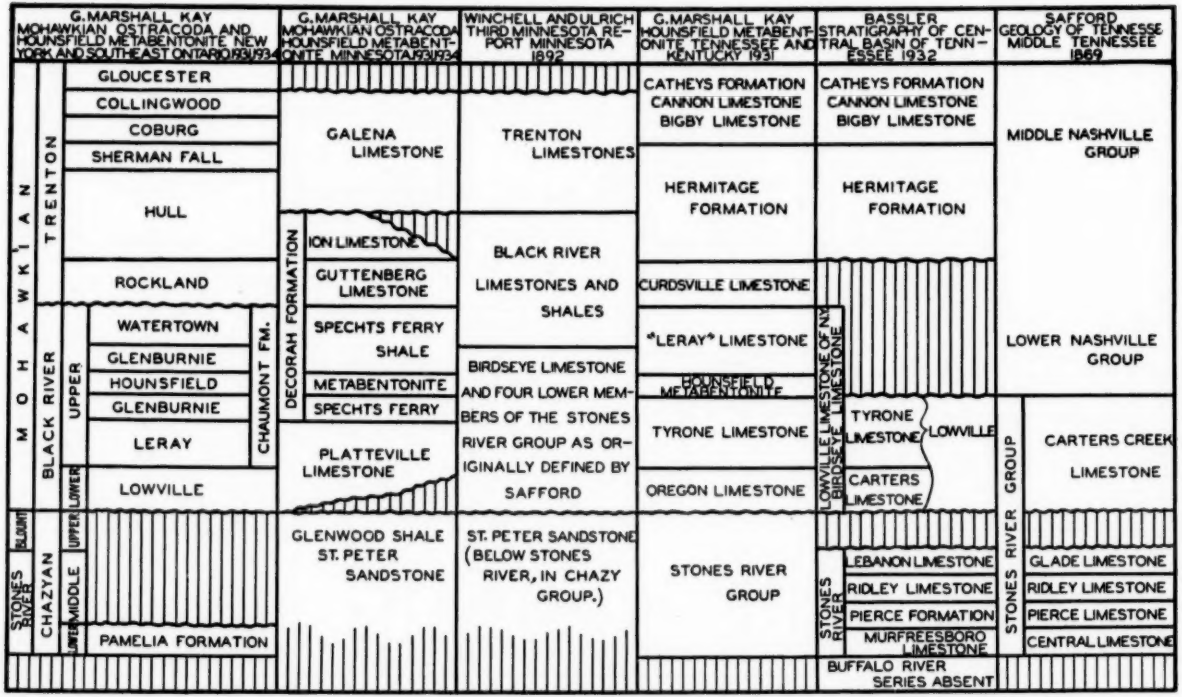


FIG. 4

According to Bassler, the "Birdseye or Lowville limestone" of New York, Kentucky, and Canada consists of three divisions: the Carters (Oregon) limestone at the base (present only on the west side of the Central Basin in Tennessee), the Tyrone limestone (the most important and widespread division of the Lowville), and the Leray limestone (absent or only locally present in Kentucky and Tennessee).[24] The Tyrone limestone has the characteristic appearance that gave the early name Birdseye limestone to the Lowville.[25]

Kay, in his paper on the Hounsfield metabentonite,[26] made some correlations for the Lowville limestone in Kentucky and Tennessee, summarized in Figure 4.

According to this interpretation, the Birdseye or Lowville limestone of Bassler is not only Lowville in age, but ranges to the top of Upper Black River time and is equivalent to the Platteville limestone and the Spechts Ferry member of the Decorah formation in the Upper Mississippi Valley.

The Birdseye limestone, therefore, is not correlated with the four lower members of the Stones River group, but the original St. Peter shell (Platteville) limestone is a correlative of the lower part of the Birdseye limestone as described by Bassler.

Ulrich believed, at the time he placed the beds overlying the St. Peter sandstone in the Upper Mississippi Valley in the Stones River group, that the Stones River beds were younger than Chazyan in age.[27] When, later, the Stones River group was determined to be of lower and middle Chazyan age, the St. Peter sandstone automatically became pre-Chazyan. In 1924 Ulrich[28] corrected himself on the age of the beds above the St. Peter sandstone and placed the Platteville and Decorah formations in the Black River group of the Mohawkian series. However, he has never changed the stratigraphic position of the St. Peter sandstone and still correlates it as pre-Stones River (pre-Chazyan) in age.[29]

[24] R. S. Bassler, *op. cit.*, pp. 60–63.

[25] R. S. Bassler, *op. cit.*, p. 61.

[26] G. Marshall Kay, "Stratigraphy of the Hounsfield Metabentonite," *Jour. Geol.*, Vol. 39, No. 4 (May–June, 1931), Table VIII.

[27] N. H. Winchell and E. O. Ulrich, *op. cit.*, pp. 108–09.

[28] E. O. Ulrich, "Notes on New Names in Table of Formations and on Physical Evidence of Breaks Between Paleozoic Systems in Wisconsin," *Wisconsin Acad. Sci. Trans.*, Vol. 21 (1924), pp. 82–83.

[29] E. O. Ulrich, "Ordovician Trilobites of the Family Telephidae and Concerned Stratigraphic Correlations," *U. S. Nat. Mus. Proc.*, Vol. 76, Art. 21 (February, 1930), correlation table, p. 73.

Hervey W. Shimer, "Correlation Chart of Geologic Formations of North America." *Bull. Geol. Soc. America*, Vol. 45, No. 5 (October, 1934), pl. 118.

In modern terminology, the beds which overlie the St. Peter sandstone at its type locality are, in ascending order, Glenwood shale, Platteville limestone, Decorah formation, and Galena limestone. Students of the subject are now in agreement that these beds above the St. Peter sandstone are all Mohawkian (Black River and Trenton) in age.

Trowbridge and Atwater state:[30]

> It has long been known that there is an important unconformity at the base of the St. Peter sandstone. So much has been written about it and so conclusive is the evidence that it can be stated confidently that this break exists and that it is an important one. The magnitude and the wide distribution of this break make it exceptionally important as a basis of classification.

The St. Peter sandstone is underlain in Minnesota by the Prairie du Chien formation of Lower Ordovician, Beekmantown age. The upper member of this formation, the Shakopee dolomite, which directly underlies the St. Peter sandstone, belongs in the Upper Canadian series of Ulrich's Canadian system.[31]

Summary.—The St. Peter sandstone at its type locality in Minnesota is immediately overlain by beds of Black River age; it is underlain by beds of Upper Canadian (Beekmantown) age; a major unconformity occurs at the base of the sandstone. The fossils contained in the sandstone are poorly preserved, embrace many new species, and are valueless for exact correlative purposes; they show a closer relationship to the beds above than to the beds below the sandstone. The only conclusive evidence to be obtained from the type locality of the St. Peter sandstone is that the sandstone was deposited during the long interval between Beekmantown and Black River time.

In Wisconsin, Iowa, and northern Illinois the same beds overlie and underlie the St. Peter sandstone as in Minnesota; the only fossils that have been recorded are worm burrows, which are without diagnostic value for age determinations.

EAST OF MISSISSIPPI RIVER

No deposits of the St. Peter series are known to occur in Tennessee, but, in Kentucky, calcareous sandstone, said by Ulrich[32] to have

[30] Arthur C. Trowbridge and Gordon I. Atwater, "Stratigraphic Problems in the Upper Mississippi Valley," *Bull. Geol. Soc. America*, Vol. 45, (February, 1934), p. 77.

[31] Arthur C. Trowbridge and Gordon I. Atwater, *op. cit.*

[32] N. H. Winchell and E. O. Ulrich, "The Geology of Minnesota," *Minnesota Geol. and Nat. Hist. Survey*, Vol. III, Pt. 2, Introduction, pp. xciii–xciv.
E. O. Ulrich, "Revision of the Paleozoic Systems," *Bull. Geol. Soc. America*, Vol. 22 (1911), p. 648.
———,"Ordovician Trilobites . . . ," *op. cit.*, pp. 73, 78.

been found in undesignated deep wells beneath at least three of the limestone formations that compose the Stones River group in central Tennessee, has been correlated by Ulrich with the St. Peter sandstone. The present writer believes that sandstone or calcareous sandstone reported from deep wells in Kentucky, even if it does occur below beds of Stones River age, need not be the St. Peter sandstone, but may as well be one of the several sandstones of Beekmantown age that are present in Arkansas, Missouri, Minnesota, Iowa, Wisconsin, and Illinois; she believes further that evidence presented for the pre-Chazyan age of the supposed St. Peter sandstone in Kentucky is inconclusive, and that considerable doubt accompanies a pre-Chazyan age determination for the St. Peter sandstone, if represented, in Kentucky.

Isabel Wasson concludes "that it is very doubtful whether the St. Peter sandstone exists in Ohio"[33] and shows that whether the beds below the Black River-Trenton sequence in the Friend well (located near the axis of the Cincinnati arch) are tied westward to the Prairie du Chien formation in the Upper Mississippi Valley, or southward to the Knox dolomite in Tennessee, the uppermost part of the pre-Black River section is Upper Canadian in age and correlates with beds that occur unconformably below the St. Peter sandstone. In the cross sections that accompany her paper, Mrs. Wasson shows the St. Peter sandstone lensing out along the west flank of the Cincinnati arch, an interpretation that seems to the present writer logical and reasonable.

The St. Peter sandstone series is absent in the middle and southern Appalachian region and in the northern Appalachian valley. Butts,[34] Ulrich,[35] and Shimer[36] consider that the place for the absent St. Peter sandstone series in the eastern part of the United States is between beds of Beekmantown and Chazyan age; the present writer believes that it is as logical to assume that the unconformity between the Chazyan and Black River beds may represent the stratigraphic position of the St. Peter sandstone series.

OZARK REGION

No fossil evidence whatever exists in any of the formations included in the St. Peter-Buffalo River series (the Everton, St. Peter,

[33] Isabel B. Wasson, "Sub-Trenton Formations in Ohio," *Jour. Geol.*, Vol. 40, No. 8 (November–December, 1932), pp. 676, 677.

[34] Charles Butts, "Geology of Alabama," *Alabama Geol. Surv. Spec. Rep. 14* (1926), pp. 101, 80.

[35] E. O. Ulrich, "Ordovician Trilobites . . . ," *op. cit.*, correlation table, p. 73.

[36] Hervey W. Shimer, *op. cit.*, Pl. 118.

Joachim, and Jasper formations) at their outcrops in the Ozark region,[37] for placing this series between the Beekmantown and Chazyan periods of the New York section, and so placing them is entirely unwarranted on paleontologic grounds. The Plattin limestone and immediately succeeding beds in the Ozark region occupy approximately the same part of the geologic column as the Platteville, Decorah, and Galena formations in the Upper Mississippi Valley. Ulrich's reference[38] of the Plattin limestone to the Ridley limestone member of the Stones River group was, therefore, erroneous, just as the designation of the beds overlying the St. Peter sandstone in Minnesota as Stones River was erroneous. Ulrich corrected the error in regard to the age assignment and correlation of the Plattin limestone with the Ridley, in his "Revision,"[39] but did not correct his assumption of a pre-Chazyan age for the Buffalo River series. In the Ozark region the Buffalo River or St. Peter series is underlain by beds correlated as Upper Canadian in age.[40]

Stratigraphic and paleontologic evidence in regard to the position and age of the St. Peter sandstone and series in the Upper Mississippi Valley and Ozark outcrops serves only to show that these beds are post-Beekmantown, pre-Black River in age.

OUTCROPS IN OKLAHOMA

Numerous Ordovician outcrops are present in Oklahoma, some in the northeastern part of the state and many in the mountain chains across southern Oklahoma. Those in northeastern and south-central Oklahoma, only, are discussed in this paper.

The outcrops in northeastern Oklahoma are really on a part of the Ozark uplift and should correlate with the St. Peter series as exposed in the Ozarks. A gap of several miles occurs, however, between the outcrops in northwestern Arkansas and northeastern Oklahoma; hence the outcrops can not be traced continuously at the surface between the two areas, and no uniformity of opinion exists among stratigraphers as to their correlation.

[37] E. O. Ulrich, "Determination and Correlation of Formations," in a Bulletin by G. I. Adams, assisted by A. H. Purdue and E. F. Burchard, "Lead and Zinc Deposits of Northern Arkansas," *U. S. Geol. Survey Prof. Paper 24* (1904), pp. 95–97.

A. H. Purdue and H. D. Miser, "Eureka Springs-Harrison, Arkansas-Missouri," *U. S. Geol. Survey Atlas Folio, 202* (1916), pp. 6, 8.

C. L. Dake, "The Problem of the St. Peter Sandstone," *Univ. Missouri School Mines and Met. Bull.*, Vol. 6, No. 1 (August, 1921), pp. 26, 28.

[38] E. O. Ulrich, "Determination and Correlation of Formations," *op. cit.*, pp. 95–97.

[39] E. O. Ulrich, "Revision of the Early Paleozoic Systems," *op. cit.*, p. 466.

[40] E. O. Ulrich, "Ordovician Trilobites . . . ," *op. cit.*, p. 80.

Ordovician rocks crop out in the Arbuckle Mountains in south-central Oklahoma, but a different facies of Ordovician deposition is found on the north and south flanks of the mountains; many beds can not be carried across at all, others are correlated with the greatest difficulty and their correlation is subject to widely variant opinions. Two different outcrops a short distance apart, even on the same flank of the mountains, may exhibit such different facies that they can not be certainly correlated with one another.

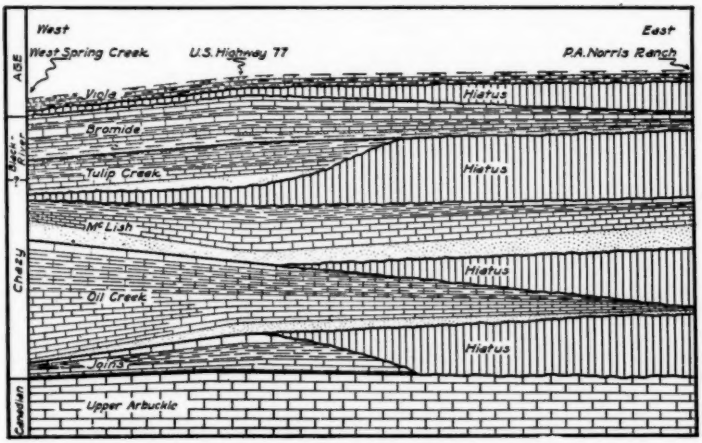


FIG. 5.—Decker's correlations in Arbuckle Mountains, Oklahoma. Diagram showing age, thickness, and relation of formations of Simpson group together with extent and position of unconformities. *Oklahoma Geol. Survey Bull. 55* (1931), p. 16.

The Ordovician beds are buried by several thousand feet of younger sediments in the area between the Arbuckle Mountains and the northeastern Oklahoma-Ozark region outcrops, as well as northward from the Arbuckle Mountains toward the outcrops in the Upper Mississippi Valley.

The outcrops in Oklahoma have been described by several writers[41] at various times since the early nineteen hundreds, but opinions

[41] J. A. Taff, "Atoka, Indian Territory (Oklahoma)," *U. S. Geol. Survey Atlas Folio 79* (1902).
———, "Tishomingo, Indian Territory (Oklahoma)," *ibid., Folio 98* (1903).
———, "Preliminary Report on the Geology of the Arbuckle and Wichita Mountains in Indian Territory and Oklahoma," *U. S. Geol. Survey Prof. Paper 31* (1904). Reprinted as *Oklahoma Geol. Survey Bull. 12* (January, 1928).
———, "Tahlequah, Indian Territory (Oklahoma)-Arkansas," *U. S. Geol. Survey Atlas Folio 122* (1905).

expressed in the literature as to the age, proper relationship, and correlation of these sediments are so widely variant, controversial, and

Ulrich's correlations for Oklahoma

1932

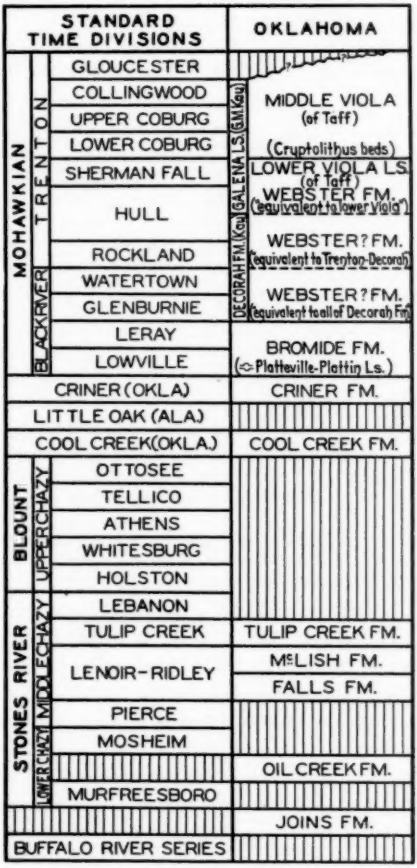


FIG. 6

confusing that no one can, at the present time, with any degree of certainty, correlate the outcrops in the Arbuckle Mountains with

each other, or correlate them with those in northeastern Oklahoma, the Ozark region, and the Upper Mississippi Valley.

Ulrich has said[42] that in 1911, when he first used the term, Bromide was restricted to beds in the Arbuckle Mountains corresponding in age with the Plattin and the Platteville. In 1929[43] he said that for the past 2 years he had included in the Bromide all beds of Black River and Trenton age that were deposited in the Arbuckle Mountains. Then in 1932[45] he again restricted the use of the term Bromide to beds equivalent to the Plattin and the Platteville and set up the Criner and Cool Creek formations as older than Black River, although Decker includes them in the Bromide and considers them Black River in age.[44] Ulrich considers[45] the Tulip Creek formation to be upper middle Chazyan in age; Decker believes[46] it is closely related to the Bromide, that the upper part is Black River and the lower part is upper Chazyan. What, then, is the base of the Bromide formation, the base of the Black River sediments, and the age of the Tulip Creek formation?

From 1927 to 1929, Ulrich included all beds of Trenton age deposited in the Arbuckle Mountains in the Bromide formation. In 1932,[47] he set up the Webster formation of late Black River and early

E. O. Ulrich, "Revision of the Early Paleozoic Systems," *op. cit.*

C. L. Dake, *op. cit.*

Charles N. Gould, "Index to the Stratigraphy of Oklahoma," *Oklahoma Geol. Survey Bull. 35* (September, 1925).

Charles Butts, *op. cit.*

E. O. Ulrich, "Fossiliferous Boulders in the Ouachita 'Caney' Shale and the Age of the Shale Containing Them," *Oklahoma Geol. Survey Bull. 45* (November, 1927).

E. O. Ulrich, "Ordovician Trilobites . . . ," *op. cit.*

Ira H. Cram, "Oil and Gas in Oklahoma, Cherokee and Adair Counties," *Oklahoma Geol. Survey Bull. 40-QQ* (May, 1930).

Charles E. Decker, "Simpson Group of Arbuckle and Wichita Mountains, Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 12 (December, 1930), pp. 1493–1505.

Charles E. Decker and C. A. Merritt, "The Stratigraphy and Physical Characteristics of the Simpson Group," *Oklahoma Geol. Survey Bull. 55* (June, 1931).

E. O. Ulrich, "The Simpson Group; Divisible into Eight, Not Only Five, Valid Formational Units," unpublished paper read before the Geological Society of America (December, 1932).

R. S. Bassler and Betty Kellett, "Bibliographic Index of Paleozoic Ostracoda," *Geol. Soc. America Spec. Paper 1* (1934), correlation chart, p. 48.

[42] E. O. Ulrich, *op. cit.*

[43] E. O. Ulrich, letter of November 11, 1929, quoted by Charles E. Decker and C. A. Merritt, "The Stratigraphy and Physical Characteristics of the Simpson Group," *Oklahoma Geol. Survey Bull. 55* (June, 1931), p. 40.

[44] Charles E. Decker and C. A. Merritt, *op. cit.*, p. 40.

[45] E. O. Ulrich, "The Simpson Group; Divisible into Eight, Not Only Five Valid Formational Units," *op. cit.*

[46] Charles E. Decker and C. A. Merritt, *op. cit.*, pp. 37, 38.

[47] E. O. Ulrich, *op. cit.*

Trenton age, saying it correlates with the Decorah formation of the Upper Mississippi Valley and with Taff's lower Viola. Taff said[48] the lower Viola is latest Black River and earliest Trenton in age, but he correlated it with beds in Minnesota now considered of lower Trenton age. What, then, is the top of the Bromide formation, what is the Webster formation, and what is the relationship of the Webster formation to the Minnesota section?

What is the exact (section, township, and range) type locality of each proposed formation in the Simpson group?

What is the measured section at the type locality of each formation?

Is there evidence of erosion at the top and/or overlap at the base of each formation?

How many conglomerates are there in the group, and what is the stratigraphic position of each?

What is the distribution of each formation?

How many of the proposed formations are present on both the southwestern and northeastern flanks of the Arbuckle Mountains, and which ones are absent on one flank or the other?

How persistent in detail are the members of each formation laterally?

What fossils are contained in each numbered bed of each formation?

When a formation is present on both flanks, are its individual members exact correlatives, bed for bed?

Into how many formations should the Simpson group really be divided?

What is the age of each?

What is the relationship of each to the standard time divisions?

These questions seem elementary, yet the answers are unknown, or, if known, are unpublished. It is obvious that, with the information available, the outcrops alone, variable, widely separated and inadequately described as they are, will not furnish sufficient information to permit a solution of the many problems of Ordovician, and particularly St. Peter, stratigraphy.

BURIED SEDIMENTS IN OKLAHOMA

Microscopists engaged in commercial petroleum geological work in the northern Mid-Continent region during the past 10 years have

[48] J. A. Taff, "Preliminary Report on the Geology of the Arbuckle and Wichita Mountains in Indian Territory and Oklahoma," *Oklahoma Geol. Survey Bull. 12* (1928), p. 24.

made very detailed studies of samples obtained from wells drilled for petroleum. These studies have been pursued along all lines of approach. Several thousand analyses have been made of the heavy detrital minerals obtained from the various sandstones and from the more arenaceous limestones and shales in the Ordovician sequence. Comprehensive suites of microfossils have been collected. Siliceous residues from the limestones and dolomite limestones have been studied. Cross sections, based on accurate sample records or "logs," have been made both of a local area confined to one oil pool and of a broad region. Subsurface maps showing the distribution of the various stratigraphic units within the buried Ordovician sequence have been prepared. The microscopists have been enabled by these broad studies to determine many unconformities and disconformities, and, therefore, many early periods of movement, that could not have been found from the studies of the more localized outcrops. They have been enabled to correlate groups of buried Ordovician strata over a wide area; in many places it has even been possible to correlate units within a given buried group in the local area of one oil pool.

In regard to beds of Black River age, the following facts are notable.

Black River beds are very thick. A thickness of 1,000 feet is known; they may in places be thicker, but are in most places much thinner than 1,000 feet.

The beds are, in many places, very fossiliferous, contain typical, described Black River fauna, and the faunal content is similar as to genera and species throughout the sequence.

Lithologically, the group is composed of limestones (various types), dolomite limestones, green, plastic shales, here and there dark gray-to-black, even maroon shales, and sandstones. Within the group the lithologic character remains the same throughout the sequence.

So many disconformities, off-laps, and overlaps exist in the sequence that many of the individual members may be absent, those present may vary even from well to well, and at no one locality has the complete sequence been seen.

The Black River beds can be correlated as a group from district to district, but detailed bed-for-bed correlations, even from well to well, in some places can be made only with the greatest difficulty.

The difficulties of correlating the Black River beds apply also (or perhaps apparently apply only because they have less frequently been encountered by wells drilled for petroleum) to the pre-Black River, Ordovician beds.

It is impossible to give a type, complete, buried Ordovician sequence from one well, because no one well has encountered a complete sequence. The sequence given in Figure 7 is a composite—it is

to be understood that any or several of the members may be absent. No thicknesses are given because the thicknesses are so variable. The names applied to the various buried groups are, for the most part, local oil-field terms.

Beds as far down as the base of series 8 are Black River in age, on paleontologic evidence, and Black River deposition may have begun at the base of bed 7. An unconformity occurs at the base of bed 7.

The heavy-mineral analyses of bed 7 as a group are similar in every respect to those that have been made of the Burgen sandstone

		SYLVAN SHALE.
VIOLA LIMESTONE (TAFF)		FERNVALE LIMESTONE.
		VIOLA LIMESTONE ("CRYPTOLITHUS" LIMESTONE).
		"WEBSTER" MEMBER.
SIMPSON FORMATION (TAFF)	SERIES 10	"BROMIDE" LIMESTONES, DOLOMITE LIMESTONES, GREEN SHALES, THIN STRAY SANDSTONES.
	BED 9	"FIRST BROMIDE" SANDSTONE.
	SERIES 8	GREEN SHALE, LIMESTONE, DOLOMITE LIMESTONE.
	BED 7	"WILCOX" SANDSTONE.
	SERIES 6	"DARK GREEN SHALE" ZONE.
	SERIES 5	"FIRST MIXED" ZONE.
	BED 4	"SCHOOL-LAND" SANDSTONE.
	SERIES 3	"SECOND MIXED" ZONE.
	BED 2	"KINTER" ("JOHNSON") SANDSTONE.
	BED 1	"STAMPER" LIMESTONE.
ARBUCKLE LIMESTONE GROUP ("SILICEOUS" LIMESTONE)		

FIG. 7

in northeastern Oklahoma, the St. Peter sandstone in Arkansas east of Jasper, the St. Peter-Everton sandstone group in Missouri, the lower part of the St. Peter sandstone in Iowa, and the lower part of the St. Peter sandstone as exposed on the campus of the University of Minnesota at Minneapolis, and all of these sandstones have almost certainly had a common origin and depositional history.

These comparisons were made possible because of the fact that, whenever time and opportunity have permitted, commercial stratigraphers have applied their usual detailed microscopic methods not only to well samples but also to samples collected in the field from Ordovician outcrops in Oklahoma, in the Ozark region, and the Upper Mississippi Valley. Enough work of this nature has been done to show its value and to permit some comparisons between the surface and buried sediments. *These are entirely tentative comparisons.*

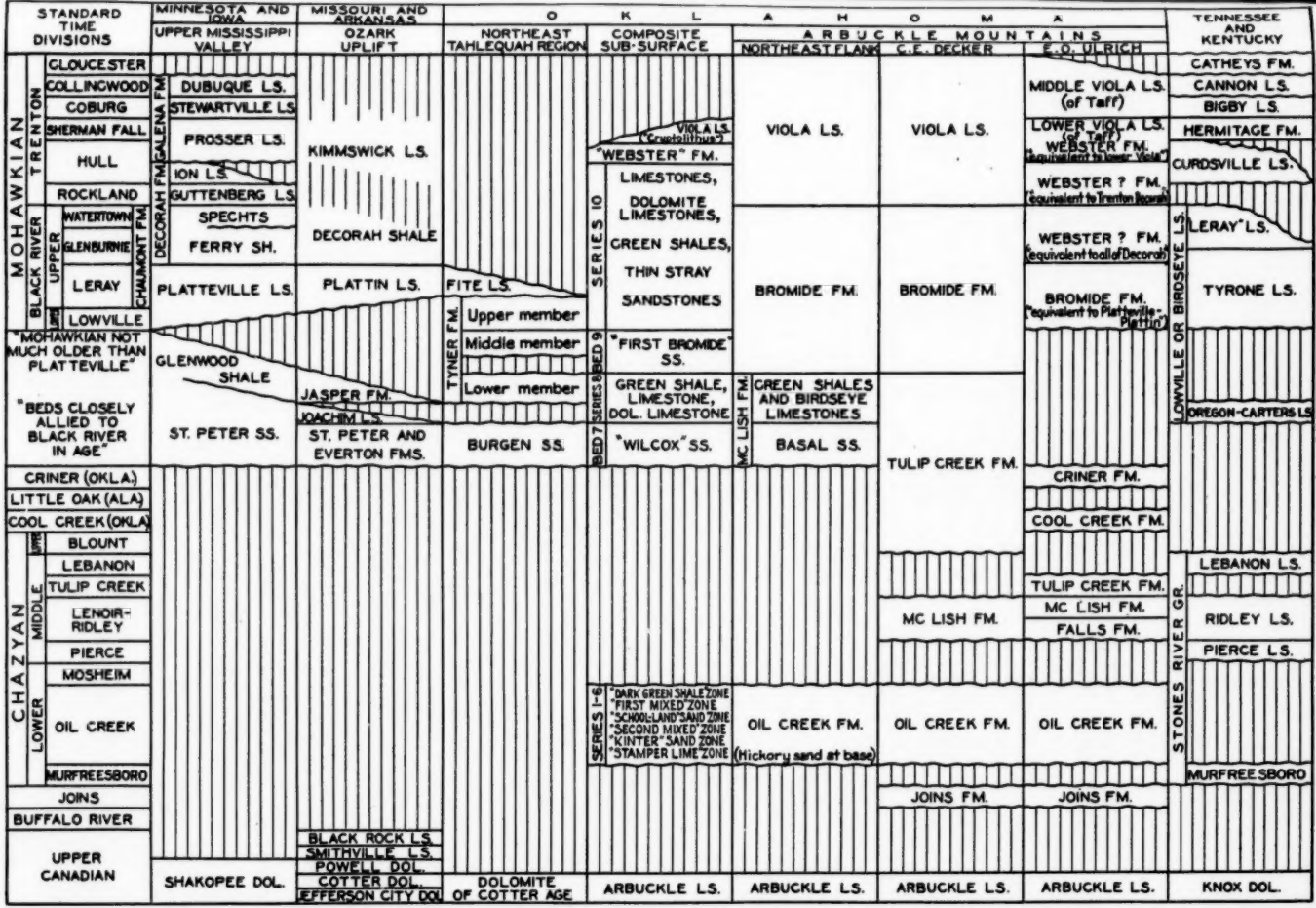


FIG. 8.—Tentative surface and subsurface correlations of St. Peter sandstone group and associated beds.

SUMMARY AND SUGGESTIONS

The one thing which can not now be done with certainty is to correlate the well defined subsurface Ordovician groups with the outcrop formations as described in various publications. The cause of this difficulty is probably two-fold: first, the confusion and controversies, in regard to the proper surface mapping, found in the literature published by the surface stratigraphers; second, the fact that the surface beds, as described, have not been mapped and studied in as great detail, or by the same methods as applied to the subsurface beds, and they have been mapped and described by stratigraphers entirely unfamiliar with the subsurface occurrences of the beds.

If Ulrich's latest restriction be adopted, that the Bromide formation should include only beds equivalent to the Plattin-Platteville limestones, a series of beds of controversial age and correlation occurs at the outcrops below the restricted Bromide and above beds definitely correlated with the Chazyan, Stones River group. Various parts of this series of doubtful beds have been called Bromide, Criner, Cool Creek, and Tulip Creek. Decker considers them all, except the lower Tulip Creek, to be Black River in age; Ulrich makes all of them below the restricted Bromide older than Black River. The Criner and Tulip Creek sediments are limited to the Criner Hills and the southwestern flank of the Arbuckle Mountains; according to Ulrich, the Cool Creek is present on both the southwestern and northeastern flanks. Sandstones are present in the doubtful series and a thick sandstone occurs at the base of the Tulip Creek wherever the Tulip Creek is present.

The McLish formation has been correlated with the Lenoir-Ridley limestone chiefly because of the presence of a birdseye-like limestone and the abundance of *Maclurites magna*. But as several birdseye-like limestones are present in the Ordovician sequence, some of which are Black River in age or are underlain by known Black River beds, a birdseye limestone in itself is not an indicator of a Lenoir-Ridley correlative. As *Maclurites magna* has been reported from the "St. Peter shell limestone" in Minnesota[49] and from the Kimmswick limestone in Missouri,[50] both younger than Stones River, the presence of *Maclurites magna* is not an infallible proof that the beds containing it are Stones River in age. Two errors have been made in correlating the beds in Minnesota and in the Ozark region

[49] N. H. Winchell and E. O. Ulrich, "The Geology of Minnesota," *Minnesota Geol. and Nat. Hist. Survey*, Vol. III, Pt. 1, p. xxvi.

[50] John A. Gallaher, "Preliminary Report on the Structural and Economic Geology of Missouri," *Missouri Bur. Geol. and Mines*, Vol. 13 (1900), Section of Ordovician, p. 109.

above the St. Peter sandstone with the Stones River group in Tennessee; these errors were made presumably because of the presence of birdseye-like limestones in the miscorrelated beds, and possibly because of misidentification or misinterpretation of the contained fauna. To the writer, it seems remotely possible that the McLish beds, likewise, may have been miscorrelated, and that possibly the McLish formation is not Stones River in age.

A thick and widespread pelecypod-bearing, blanket sandstone, lithologically and in heavy-mineral content entirely similar to the sandstones in the St. Peter and "Wilcox" sandstone series, occurs at the base of the McLish formation. This sandstone is quarried at Roff, Oklahoma, for glass manufacture, and at Sulphur, Oklahoma, for rock asphalt.

Paleontologic evidence indicates that the beds of controversial age at the outcrops (Criner, Cool Creek, Tulip Creek), the buried "Wilcox" sandstone series, and the Burgen-Tyner series of the northeastern Oklahoma outcrops are closely related in age to Black River beds, just as the St. Peter series in Minnesota and the St. Peter-Buffalo River series in the Ozark region are said[51] to be more closely allied to the overlying Black River beds than to the underlying Canadian strata.

The St. Peter series may or may not be present in Oklahoma, but probably is present. When the surface beds have been mapped and studied in as great detail, by the same methods as applied to the subsurface beds and by subsurface stratigraphers entirely familiar with the buried occurrences of the Ordovician beds, then an intelligent attempt can be made to correlate the buried sediments with those exposed at the outcrops, and to correlate the outcrops in the Arbuckle Mountains with those in northeastern Oklahoma, the Ozark region, and the northern Mississippi Valley. Then, and only then, can the presence and stratigraphic position of the St. Peter sandstone and the Buffalo River series be established in Oklahoma. When the stratigraphic position of the St. Peter series (if present) can be established in Oklahoma in relation to the other Ordovician sediments, its exact age can probably more nearly be determined.

The writer wishes to suggest that, when sufficiently accurate and detailed studies have been made of the outcrops and the buried Ordovician sediments, the St. Peter-Buffalo River series will be found in Oklahoma to underlie beds of the same Black River age that it does

[51] N. H. Winchell and E. O. Ulrich, *op. cit.*, Vol. III, Pt. 2, Introduction, pp. xci–xcii.

E. B. Branson and M. G. Mehl, "Conodont Studies No. 1," *Univ. Missouri Studies*, Vol. 8 (1933), p. 20.

in the Ozark region and in the Upper Mississippi Valley; further, that the beds of controversial age at the Arbuckle Mountain outcrops between the base of the restricted Bromide formation and the top of the known Chazyan sediments, including possibly the McLish-(Falls?) formation, may represent in Oklahoma expanded equivalents of the Everton, St. Peter, Glenwood, Joachim, and Jasper formations.

Should these suggested correlations eventually be proved correct, the St. Peter series will, in Oklahoma, overlie beds of Chazyan, possibly lower Chazyan, age.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 19, NO. 8 (AUGUST, 1935), PP. 1131-1147, 6 FIGS.

GOVERNMENT WELLS OIL FIELD, DUVAL COUNTY, TEXAS[1]

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San Antonio, Texas

ABSTRACT

The Government Wells field of Duval County, southwest Texas, has been proved one of the most economically attractive shallow fields in the state. The paper presents a short history of the field, its past development, drilling, and operating conditions. The surface and subsurface geology of the area is explained, including data on various sand members. Completion of the wells, bottom-hole pressures, potentials, operating methods, water encroachment, and ultimate recovery are discussed.

INTRODUCTION

The fields of the Laredo district in southwest Texas have for the past 14 years been very attractive to operators seeking shallow oil. Most of the pools prior to the discovery of the Government Wells field were much smaller in area and in productiveness and generally have not produced wells with the initial flows and pressures that are encountered in this field. The Government Wells field has thus gained considerable prominence, and much interest is manifest throughout the general area in which the field is located.

The surface geology as shown in Figure 2 was mapped by K. H. Crandall of The California Company. The bottom-hole pressure map (Fig. 6) is a result of data compiled in the field under the supervision of Ed. Rach of the Texas State Railroad Commission.

LOCATION

The area under consideration is in the Laredo district of south Texas in the trend of the escarpment fields. It is situated in Duval County 30 miles west of San Diego, the County seat, and approximately 120 miles south and slightly west of San Antonio. The nearest town is Freer, immediately east of the field. The area includes parts of 15 sections of what was formerly known as the Rosita Ranch of western Duval County, and acquired the name of Government Wells

[1] Presented in part before the San Antonio Section of the Association, at the Laredo meeting, November 3, 1934; and before the Association at the Wichita meeting, March 22, 1935. Manuscript received, March 18, 1935.

[2] Consulting geologists, 1720 Alamo National Bank Building.

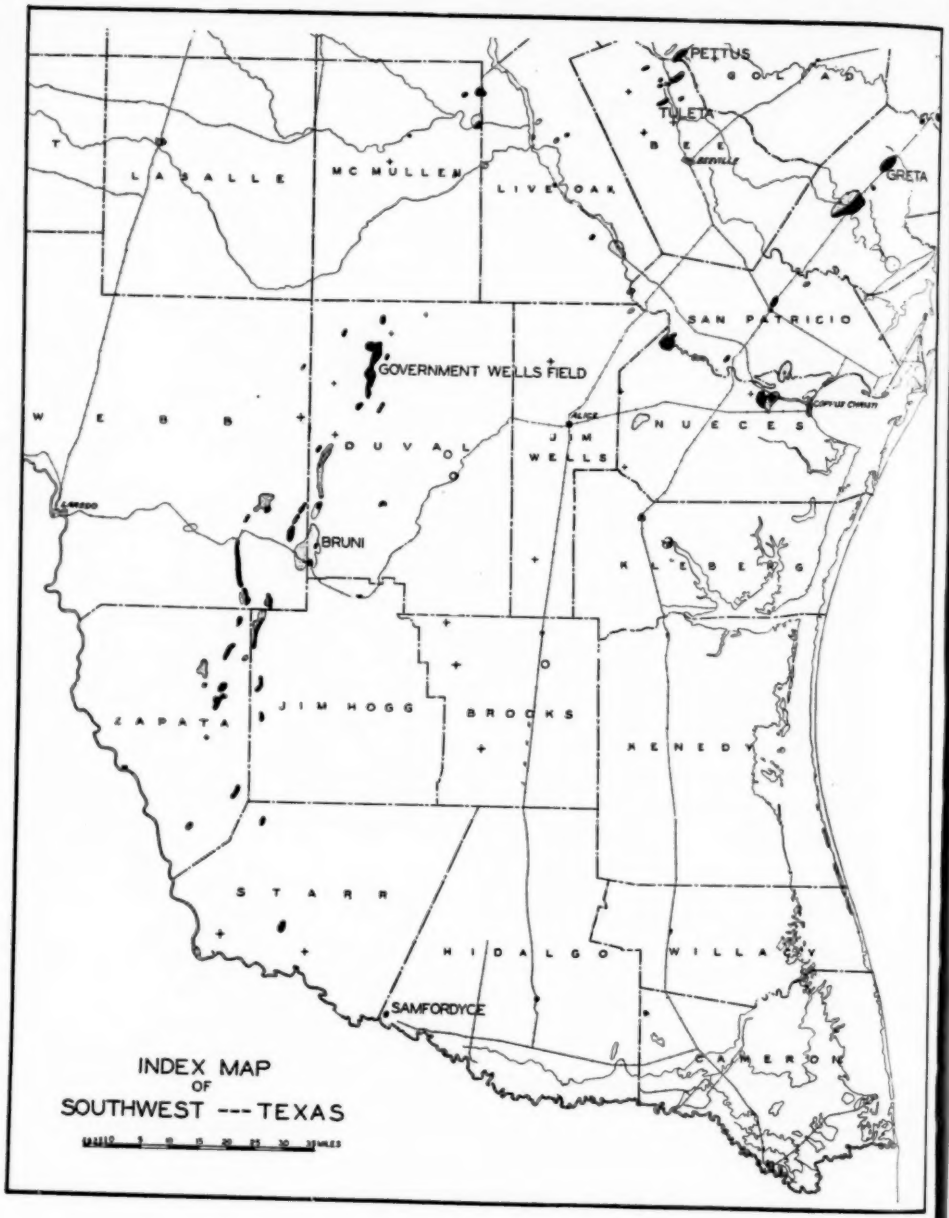
PETTUS
TULETA
GRETA
LA SALLE
MC MULLEN
LIVE OAK
SAN PATRICIO
GOVERNMENT WELLS FIELD
WEBB
DUVAL
JIM WELLS
NUECES
BRUNI
KLEBERG
ZAPATA
JIM HOGG
BROCKS
KENEDY
STARR
HIDALGO
WILLACY
SAMFORDYCE
CAMERON
INDEX MAP
OF
SOUTHWEST --- TEXAS

FIG. 1

from the old water wells in the northern end of the field, drilled several years ago by the Government to obtain water for the district.

TOPOGRAPHY

The main topographic feature is the Reynosa Escarpment about 2.5 miles east of the easternmost edge of the field. It has a general northeastward trend rising 100–150 feet above the average elevation of the area. From the high point on the west face of the scarp the average surface elevation gradually decreases southeast at the rate of 15 feet per mile.

Other than the escarpment, the topography consists of low rolling hills with here and there broad flat valleys. These gradually merge into the flat featureless topography of the district 30 miles east of Government Wells.

Except for a few scattered areas which have been cultivated, the region is covered with a fairly thick growth of mesquite, cactus, and brush.

HISTORY OF DEVELOPMENT

In 1927 a test was drilled by the Schlesinger Oil Corporation in Survey 76, approximately 1.5 miles east of the Old Government Wells pool. The casing in this well was set on the Upper Government Wells sand. The well produced about 3 barrels per day, and was later abandoned. The operators who drilled this test then located a second well farther west, in the northeast quarter of Section 60, but it was lost after some oil sand was cored in the Government Wells horizon. Following this, 3 additional tests, all of which proved failures, were drilled in surveys 60 and 250, each of which was west and up the dip from the preceding test. The sixth well, located on the Norton land in Survey 250, was completed as the discovery in August, 1928, with an initial production of 135 barrels per day from a total depth of approximately 2,350 feet. Following this discovery approximately 60 wells were drilled, proving 300 acres of oil land. These wells were completed in both the Upper and Lower Government Wells sand, although the initial production of any well was not more than 150 barrels per day, the average being 75.

In November, 1930, the Duval Oil Corporation completed their Bishop Land and Cattle Company No. 1, in Survey 135, flowing 100 barrels per hour from a depth of 2,308 feet. This well opened the part of the field known as the South Government Wells pool, and was the first large well completed in this field. During the latter part of 1930 and the early part of 1931 this part of the field was developed north and south of the discovery well through sections 58 and 135.

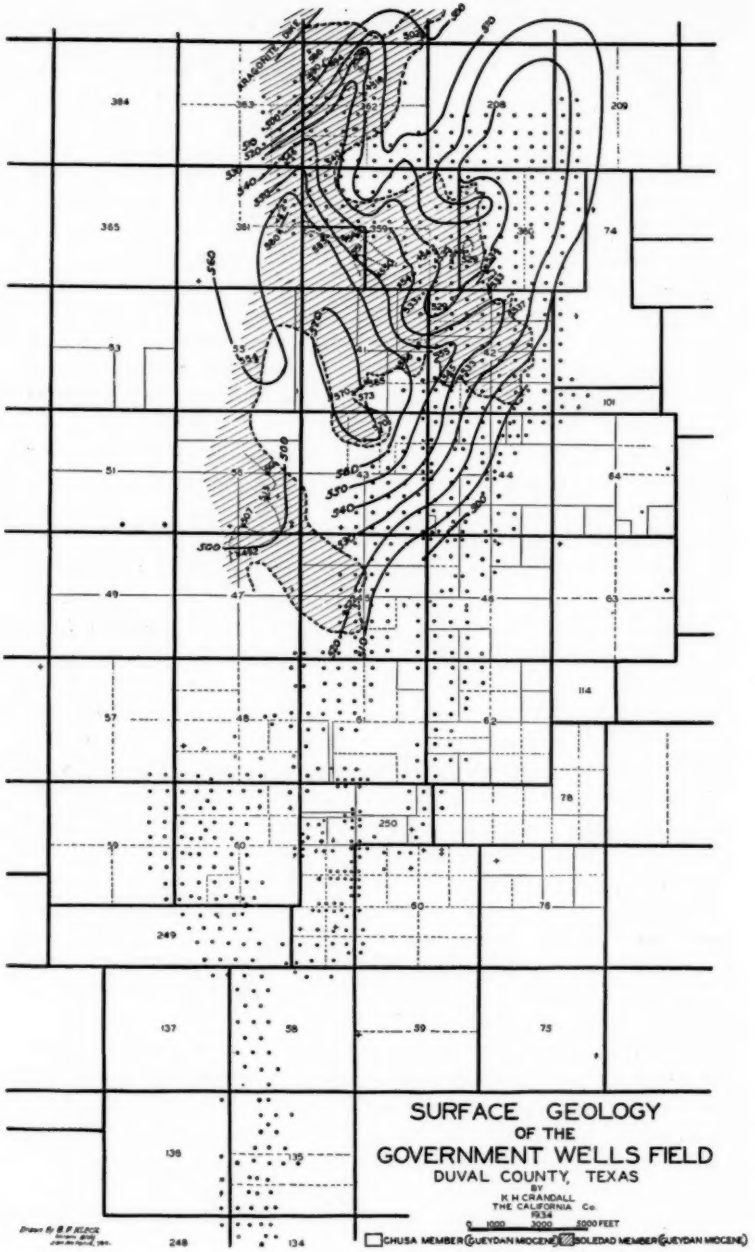
SURFACE GEOLOGY
OF THE
GOVERNMENT WELLS FIELD
DUVAL COUNTY, TEXAS
BY
K.H. CRANDALL
THE CALIFORNIA Co.
1934
0 1000 3000 5000 FEET
CHUSA MEMBER (UPPER EOCENE) SOLEDAD MEMBER (UPPER EOCENE)

FIG. 2

The next major extension was made in May, 1932, when Suttles *et al.* (later the San Diego Oil Corporation) completed Bennet No. 1 in Survey 46 at 2,330 feet, flowing 75 barrels per hour. Rapid development took place in all directions from this well, eventually connecting the three pools, Old, North, and South Government Wells, and proving a total of 5,500 acres of oil land.

In 1927 the Magnolia Petroleum Corporation drilled two wells in Survey 51 west of the North pool. The first was completed at 4,094 feet as a gasser with several barrels of naphtha per day, and the second test, ½ mile farther east, was a failure. As this discovery is the only well producing from a horizon below the Government Wells sand, it furnishes important evidence of deeper production in the area.

SURFACE GEOLOGY

STRATIGRAPHY

The formations cropping out within the area of the field and immediately adjacent comprise the upper two members of the Catahoula Tuff, of Miocene age. The uppermost, or Chusa, series consists almost entirely of pink-to-pinkish buff, massive, tuffaceous clay in some places resembling a loess deposit. This formation is so massive and characterized by its lack of bedding that any detail work within the area of its outcrop is almost impossible.

The Soledad, or middle member of the Catahoula series, cropping out in the central western part of the North pool, consists of gray-to-brown, medium-to-coarse sandstones and conglomerates containing much volcanic material interbedded with tuffaceous clays similar to those of the Chusa formation. Considerable fine-grained sandy tuff and tuffaceous sands also occur throughout the Soledad beds. Perhaps the best exposure of this member is in the northern end of the field in Section 359 just north of the old Government water wells, where the hilly topography affords some good outcrops.

STRUCTURE

Inasmuch as neither the Chusa nor the Soledad formation within the area contains key beds on which detail field work could be done, it was necessary to run elevations on the contact of the two to determine the surface structure. This contact, somewhat gradational and difficult to trace, has a regional strike of N. 25° E. with a dip of about 90 feet per mile southeast. These are interrupted in the North Government Wells field by some irregularities due to structure, as shown in Figure 2. As a whole the structure appears as a broad nose or terrace with the high part lying in sections 41, 42, and 359. Farther

north there appear to be two large noses and one small nose plunging north with a generally east strike indicating closure on the north end of the field. A strong west dip, apparently indicative of structure, was recorded in the eastern part of Section 361.

On the south, in Section 41, an area of slight closure was mapped, and in the southeast quarter of Survey 56 a structural "low" exists. Thin sandstone beds cropping out here, which are similar to, and were correlated with, sandstones at the top of the Soledad farther east, form the basis for mapping these irregularities in the general structure.

With the possible exception of two localities, one in Section 96 and the other in the southwest corner of Section 360, very little, if any, faulting exists. Trending N. 45° E., diagonally across Section 96, is an aragonite vein or dike which apparently forms a fault contact between the Soledad and the Chusa formations. The displacement, probably very small, was up on the west and down on the east side of the vein. In Section 360, slickensiding occurs which is possibly accompanied by a very small amount of faulting. The strike in this particular place is also northeast; however, no reasonable amount of offsetting has taken place on the Soledad-Chusa contact so that its significance is not important.

By comparison of the maps, the surface and subsurface structure of the North pool may be seen to conform very closely.

SUBSURFACE GEOLOGY

STRATIGRAPHY

From the surface to a depth of about 1,600 feet the formations drilled through consist of pink and bluish green clays, gray sand, and conglomerates containing considerable tuffaceous material. These beds belong to the Gueydan formation, of Miocene, and Frio-Vicksburg, of Oligocene age. The Jackson strata, of Eocene age, containing most of the producing horizons of the Laredo district, are encountered between the depths of 1,600 and 3,000 feet, followed by the Yegua beds with a thickness of approximately 700 feet. Below these the Cook Mountain strata are found, having a total thickness of approximately 1,500 feet.

Downward from the top of the Jackson series the first sand encountered is the top of the Cole horizon at 1,700 feet. This sand contains a good volume of gas with a rock pressure of 500 pounds per square inch; however, there is apparently no oil in commercial quantities in this particular horizon as most wells which have been tested have shown either gas or salt water. The Cole horizon is 250 feet

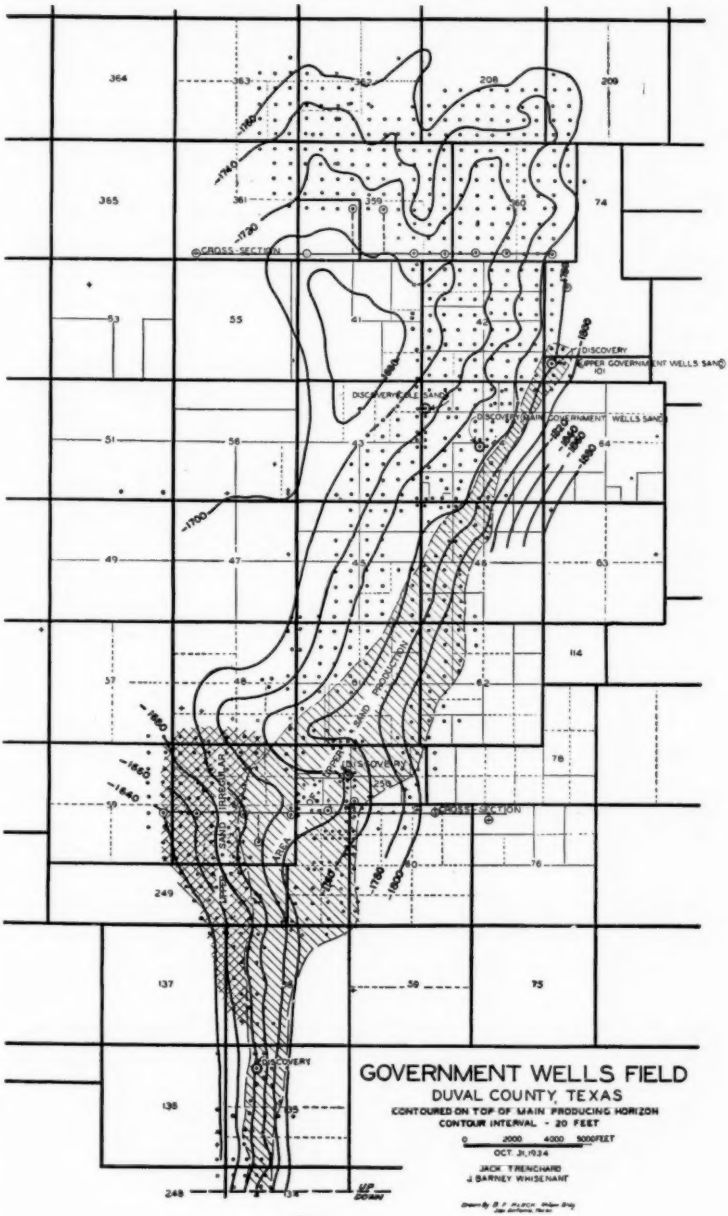
GOVERNMENT WELLS FIELD
DUVAL COUNTY, TEXAS
CONTOURED ON TOP OF MAIN PRODUCING HORIZON
CONTOUR INTERVAL - 20 FEET
0 2000 4000 6000 FEET
OCT. 31, 1934
JACK TRENCHARD
J. BARNEY WHISENANT
DISCOVERY
UPPER GOVERNMENT WELLS SAND
DISCOVERY MAIN GOVERNMENT WELLS SAND
CROSS-SECTION
UP DOWN

FIG. 3

thick and consists of alternating beds of sand and shale. The next regular producing sand, the Government Wells sand 715 feet below the top of the Cole sand, has a maximum thickness of 50 feet in the north part of the field.

About 200 feet below the top of the Government Wells sand is the Mirando City horizon, which is perhaps the most uniformly deposited sand in the entire Laredo area, as it is found in all wells in the district, whether shallow or deep. In the Government Wells field it is encountered at a depth of 2,500 feet, and in those few wells which have been drilled below the Government Wells sand, it has been found to contain an odor of oil, although no production has been obtained from this sand.

The next horizon below the Mirando City is the Pettus sand, with an interval of approximately 200 feet. Little information is available about this sand in this field, but to the writers' knowledge it contains no oil sands.

The Yegua series consists of several sands alternating with shale beds, similar to the Cook Mountain formation next below the Yegua. To date the only horizon below the Government Wells which has been found to possess possibilities of commercial production is a sand in the Cook Mountain encountered at 4,094 feet in the Magnolia Petroleum Corporation's Hahl No. 1, in Section 51, 1.5 miles west of the field. This well produced a small amount of naphtha per day with a fairly large volume of gas.

STRUCTURE

As shown on the accompanying subsurface structure map (Fig. 3), accumulation of oil and gas in this field seems to be due to a combination of folding, faulting, and lenticular sands. The south end of the field is terminated by a cross-fault with a throw of 200 feet, the downthrown area lying south of the fault. The presence of this fault was plainly determined by subsurface correlation of the Magnolia Petroleum Corporation's J. Wilson No. 4 and No. 7. Though these wells are 660 feet apart on a north-south line, the formations in No. 7, a dry hole, are 200 feet structurally lower than in No. 4, which is a producer.

This uplift caused by the cross-fault in the South pool is terminated on the northern limits of the field by a 90° change in strike of the beds due to folding, so that as a whole the subsurface structure represents a low gently folded anticline on the north, gradually merging into a monocline abutting a cross-fault on the south end. The rate of easterly dip of the producing sands is twice as great in the South as in the North pool; hence, a much narrower belt of production exists in the South pool.

On the west the Government Wells sand lenses out, so that, with the exception of the north end where folding exists, closure is afforded by the lenticular character of the sand. On the east the normal rate of dip of the Jackson strata ranges from 100 to 125 feet per mile, but the dip abruptly increases at the extreme edge of the field to 175 feet per mile.

From a regional standpoint it is evident that the normal easterly dip of the subsurface beds has been arrested to the extent of 200 feet, so that the uplift can be considered to be as much as this. The amount of closure from the highest gas well drilled to date to the oil-water edge is 100 feet, from the −1,680 to the −1,780-foot contour.

CHARACTER AND EXTENT OF PRODUCING SANDS

In general the Government Wells horizon consists of medium-grained gray sand, and with the exception of the top part, which is usually compact and well cemented, this may be classified as soft unconsolidated sand. It is so loose that extreme care must be taken during coring and drilling, as several feet may be penetrated within an extremely brief time.

The maximum thickness of the main producing horizon is 50 feet, particularly in the North pool, where the sand section appears to be unbroken by shale beds. In the South pool the pay sand consists, in some wells, of three sands separated by beds of brown shale. As these sands are locally lenticular, the thickness may vary considerably.

Producing sands in the Old field are extremely lenticular and consequently rather mediocre production was obtained from wells in this pool as compared with wells in the North and South pools. Lying 10–30 feet above the main Government Wells sand is a member having a maximum thickness of 18 feet and an average thickness of 10 feet, known as the Upper Government Wells sand. This sand is similar to the main producing sand in all respects except that it is generally more firm and compact.

The cross-hatched area on the map (Fig. 3) represents that part of the field in which the Upper sand is found productive. It may be seen to transgress laterally across the area of Lower Government Wells sand production in the Old and South fields, so that in these areas both the Upper and Lower sands produce. In the North pool the Upper horizon lenses out in surveys 44 and 46 and produces only on the extreme east side of the field.

As the permeability of the producing sand throughout the field varies considerably, it has been an important factor in the production of various wells. For instance the Lower sand, as shown on the cross

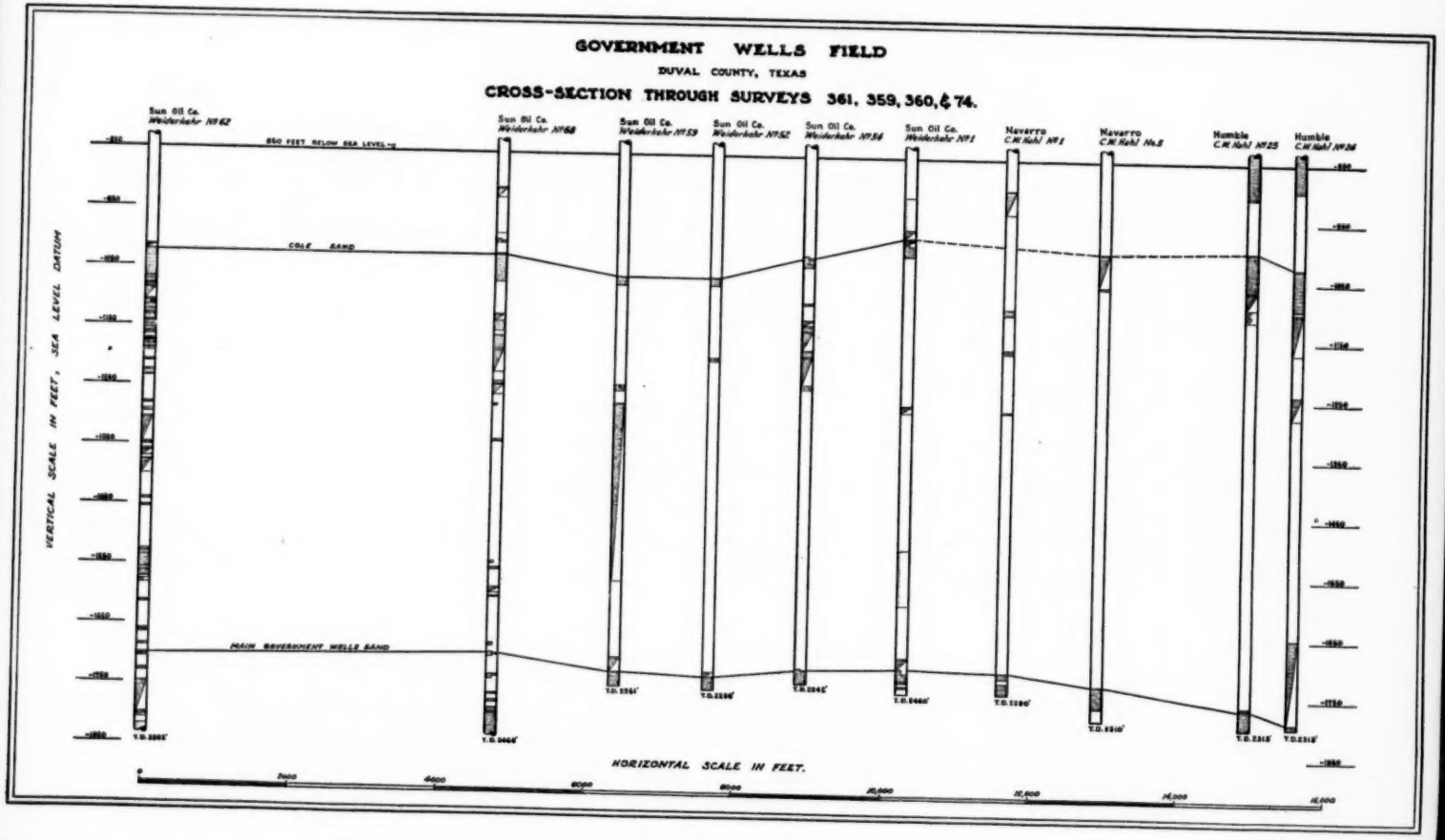
GOVERNMENT WELLS FIELD
DUVAL COUNTY, TEXAS
CROSS-SECTION THROUGH SURVEYS 361, 359, 360, & 74.
Sun Oil Co. Weiderkehr NO 62
Sun Oil Co. Weiderkehr NO 68
Sun Oil Co. Weiderkehr NO 59
Sun Oil Co. Weiderkehr NO 52
Sun Oil Co. Weiderkehr NO 54
Sun Oil Co. Weiderkehr NO 1
Navarro C.M. Kahl NO 1
Navarro C.M. Kahl No. 5
Humble C.M. Kahl NO 25
Humble C.M. Kahl NO 24
850 FEET BELOW SEA LEVEL
COLE SAND
MAIN GOVERNMENT WELLS SAND
VERTICAL SCALE IN FEET, SEA LEVEL DATUM
HORIZONTAL SCALE IN FEET.
2400
4800
8000
20,000
32,000
44,000

FIG. 4

FIG. 4

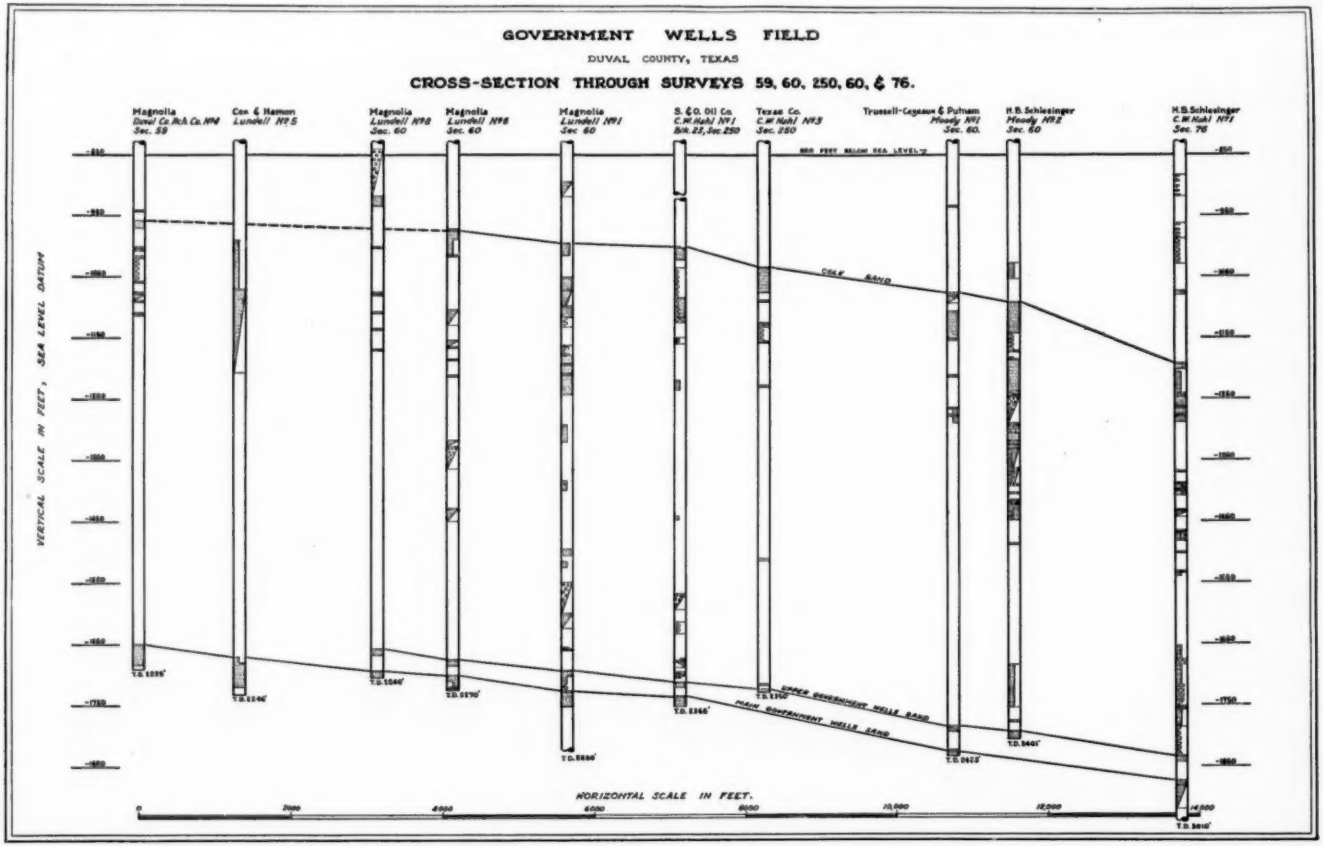
GOVERNMENT WELLS FIELD
DUVAL COUNTY, TEXAS
CROSS-SECTION THROUGH SURVEYS 59, 60, 250, 60, & 76.
Magnolia Duval Co. Rch. Co. №4 Sec. 59
Con. & Hamon Lundell №5
Magnolia Lundell №6 Sec. 60
Magnolia Lundell №6 Sec. 60
Magnolia Lundell №1 Sec. 60
S. & O. Oil Co. C.W. Kuhl №1 Blk. 23, Sec. 250
Texas Co. C.W. Kuhl №3 Sec. 250
Trussell-Legasus & Putnam Moody №1 Sec. 60.
H.B. Schlesinger Moody №2 Sec. 60
H.B. Schlesinger C.W. Kuhl №1 Sec. 76
MSL FEET BELOW SEA LEVEL
VERTICAL SCALE IN FEET, SEA LEVEL DATUM
COLE SAND
UPPER GOVERNMENT WELLS SAND
MAIN GOVERNMENT WELLS SAND
T.D. 5225'
T.D. 5240'
T.D. 5268'
T.D. 5270'
T.D. 5886'
T.D. 5350'
T.D. 5348'
T.D. 5441'
T.D. 5423'
T.D. 5610'
HORIZONTAL SCALE IN FEET.
0
2000
4000
6000
8000
10,000
12,000
14,000

FIG. 5

section (Fig. 5) through the Old field and the north end of the South pool, affords a perfect correlation with no interruption in the normal dip, and high-pressure flows have been completed in wells less than ¼ mile from wells which have been producing for 6 years.

This is also true on the west side of the Old pool, where recent completions a short distance east of old wells have shown little effect from drainage. This variation of permeability is due to the shaly nature of the sand, which many core samples have shown to contain small particles and very thin layers of shale.

DRILLING CONDITIONS AND COMPLETION OF WELLS

All wells in this field are drilled with a light type rotary rig, using the ordinary fish-tail bit throughout except in wells where extremely hard formations are encountered. One or two joints of second-hand 10-inch casing are set for surface conductor, after which a 9⅞ inch hole is drilled to within a few feet of the pay sand. The sand is then cored and 7-inch O. D. casing is cemented with 100 sacks of cement. A 5⅛-inch shop-perforated liner is set in the oil sand generally with a back-pressure valve in the bottom to prevent heaving of the sand.

The entire drilling and completion usually requires not more than 15 days, and many wells have been completed in 10 days, 3 of which are allowed for cement to set. Two-inch plain tubing with one joint of perforated, or open-ended, tubing on the bottom is the common practice for tubing the wells. Several standard types of Christmas-tree connections are used and some operators have constructed their own flowing connections with ordinary 2-inch valves and fittings.

In the early stages of development the wells were swabbed in through the casing and tubing after circulation with clear water. With sufficient gas pressure developed from various wells, the common practice is to "rock" the wells in. Upon final completion the wells are flowed through ⅛-inch and ¼-inch chokes with tubing pressures ranging from 75 to 200 pounds per square inch and with casing pressures of 800 pounds, maximum.

OPERATING METHODS

During the early development the daily allowable production per well was such that little difficulty was encountered in producing under ordinary methods, that is, by simply flowing the wells through 2-inch tubing with small chokes in the flow line. With the advent of proration, however, the allowables were so reduced (26 barrels per day) that problems of production became serious. It was found that

wells not located on the extreme western side of the field, where the gas pressure is the greatest, would not flow through 2-inch tubing at less than 4 barrels per hour. This, of course, forced the employment of methods to produce steadily or periodically on the low daily allowable.

In putting wells back on production after shutting them in, the usual method, at first, was either to swab or to rock them in. Continuous use of these methods was very injurious, due to the sands heaving into the hole, eventually causing water to break in.

Three methods are now generally used: pumping, flowing with the aid of valves, and tapered tubing. Some leases have been equipped from the start with power plants and each well rigged to pump, thereby giving a means of agitation which causes the well to start flowing. The expense of this equipment is overcome by the fact that the investment will be necessary at such time as the wells have to be pumped regularly.

The second method is the use of flow valves. Many wells are equipped with these and similar devices designed to handle the oil. These valves are set in the tubing string at intervals of 200–300 feet, with a bottom-hole choke installed about 200 feet off bottom. The choke is ordinarily either $\frac{1}{4}$- or $\frac{3}{8}$-inch in diameter. The injection of a limited amount of gas causes the oil to start rolling, inasmuch as these valves keep the oil column within the tubing constantly aerated.

The third method of production is the use of a string of tapered tubing. This practice has been confined almost entirely to the northern end of the field, where it has been quite satisfactory. The tapered tubing usually consists of a string of pipe, half of which is $\frac{3}{4}$-inch, and the other half, 1-inch. The use of the tapered tubing affords a more continuous flow and probably a smaller amount of injected gas at the start.

BOTTOM-HOLE PRESSURE AND GAS-OIL RATIO

During 1934 a rather complete hole-pressure survey was made by engineers of the Texas State Railroad Commission, under the supervision of Ed. Rach. The accompanying map (Fig. 6) is a compilation of their data showing the field as contoured on pressures with a 10-pound interval. For convenience the pressure data on both the Upper and Lower sand wells are shown on one map, and the lines have been drawn between the areas to segregate them.

The first bottom-hole pressure test was made by one of the major companies shortly after completion of the first few wells in the North pool, and, to the writers' knowledge, the pressure through the central

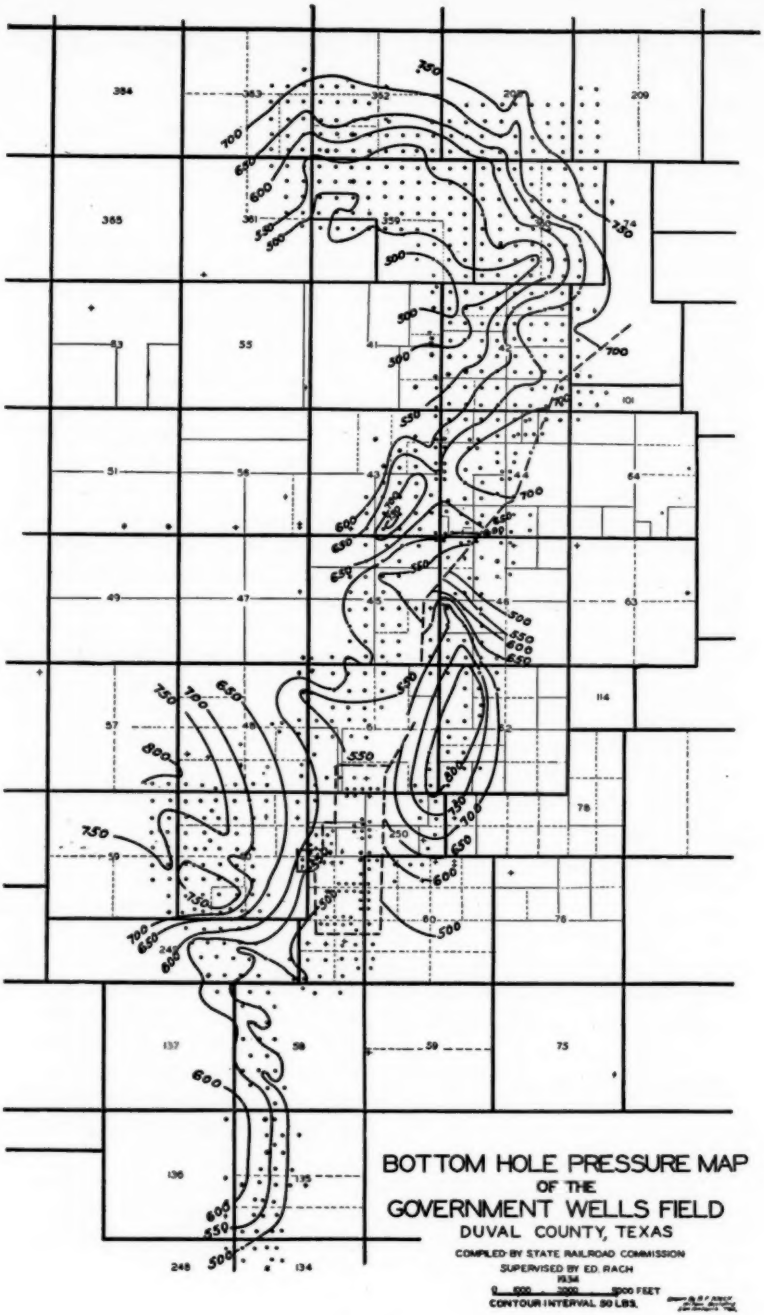
BOTTOM HOLE PRESSURE MAP
OF THE
GOVERNMENT WELLS FIELD
DUVAL COUNTY, TEXAS
COMPILED BY STATE RAILROAD COMMISSION
SUPERVISED BY ED. RACH
1934
0 1000 2000 3000 4000 FEET
CONTOUR INTERVAL 50 LBS.

FIG. 6

part of Survey 46 ranged from 850 to 875 pounds per square inch. In view of this it seems likely that the highest initial pressure did not exceed 875 pounds.

In the South pool the pressure gradually decreases from west to east or from high to structurally low wells, though in the North field the opposite is true. In other words, wells with a potentially large production have a lower bottom-hole pressure than those wells with a smaller potential; in fact, some wells producing salt water and near the edge have the highest bottom-hole pressures of any wells. This is apparently due to too rapid withdrawal of gas along the western side with resulting lower pressure here than on the eastern or water-drive side of the field. It is probable that in time this condition will adjust itself so that the pressures are more nearly equal throughout the field.

Gas-oil ratios vary according to structural location, those wells on the west or gas-oil edge generally having the highest ratios. The original ratio, as allowed by the State Railroad Commission, was 1,250 cubic feet per barrel; however, this has recently been reduced to 1,000 cubic feet. Along the east side, ratios as low as 80 have been measured, though the average is about 250. In the South pool the gas-oil ratio ranges upward from 400. It is interesting to note that in several wells lower on structure, the ratios have been higher than in wells farther up the dip. This is no doubt due to the lenticular character of the sands.

POTENTIALS

It is rather difficult to arrive at the open-flow possibilities of the field, because most operators are opposed to opening their wells fully, thus reducing the back pressure on the oil sand and allowing possible heaving.

The Texas Company's Wendt, Freer, and Johnson leases in sections 42 and 45 of the North pool showed an average of 60 barrels per hour on 2-inch tubing through a 1-inch choke. D. J. Freer No. 1, in the extreme northeast corner of Survey 45, flowed at the rate of 109 barrels per hour on a 1-inch choke. Though this is a fairly high rate for this field, many wells have initially produced 75 barrels per hour. The potential of the field for flowing wells, based on $\frac{1}{2}$-inch chokes through 2-inch tubing, is estimated at 35 barrels per hour.

WATER ENCROACHMENT

It is almost impossible to make an edge-water map of the field, because several wells throughout the field, both high and low on

structure, are producing some water. The encroachment of salt water is consequently very irregular and its presence in most of the wells depends mainly on the original depth at which the wells were completed, in addition to the method of operating after being completed.

As previously mentioned, the pay sand in this field is very susceptible to heaving, causing the wells to drill themselves deeper so that a combination of deep drilling into the sand plus particular methods of operation, such as swabbing and rocking the wells after completion, have in most wells caused premature production of salt water. The original water line was on the −1,780-foot contour.

The fact that the water appears to channel through the sand from one well to another regardless of structural position also has caused much concern to operators. Some wells have been known to increase their salt-water content suddenly from a relatively small percentage to as much as 80 or 90 per cent within a few days' time. This is apparently due to water channelling through the sand and coning in some particular well. The fact that this may occur at any time, however, does not mean that it will ruin a well so that it will have to be plugged. In one well, water suddenly coned to such an extent that it produced 90–97 per cent salt water immediately. The well has been producing steadily since this happened 3 years ago and has produced a considerable quantity of oil. In still another well the percentage of water increased from 0 to 85 per cent within two weeks time, though that particular well has produced twice as much oil since as before the intrusion of water.

It may be seen, therefore, that it is difficult if not practically impossible to estimate the average increase of salt water throughout a period of time in conjunction with the ultimate recovery.

POROSITY

The measurement of the porosity of the pay sand in the various parts of the Government Wells field has not, to the writers' knowledge, been undertaken very extensively. One of the major companies made some tests of the sand during the early stages of development and found it to have an average porosity of 26 per cent. Other laboratory tests have no doubt been made; however, this figure is probably a representative one for the porosity of the sand in the field.

ULTIMATE RECOVERY

The ultimate recovery per acre for various parts of the field will be quite different; for instance, the Old pool, which is considerably depleted, will produce about 9,000 barrels per acre, and certain leases

in the South pool have already produced as much as 15,000 barrels per acre. Both these pools were not under proration until considerable oil had been produced, though the North pool was prorated from the start. In view of this, the ultimate recovery has been estimated for each of the pools separately.

The Old pool, as previously stated, had produced the major part of its recoverable oil under ordinary conditions, as have certain parts of the South pool. Inasmuch as the Old field has been producing since 1928, enough data are available to indicate that the foregoing figure of 9,000 barrels per acre will be a fair estimate of its ultimate recovery.

In the North pool, where the sand section is uniform, it seems that the best method of estimating the ultimate recovery is by considering the sand thickness and porosity. The average thickness of saturated sand for this pool is 20 feet. If 40 per cent is an adequate figure for the amount of recovery, with a porosity of 26 per cent and a thickness of 20 feet, the ultimate production per acre would be 16,175 barrels. With a 15 per cent hazard factor for poor development and production methods, as well as for excess withdrawal of gas, which will no doubt affect the recovery, the ultimate recovery per acre for this pool should be 13,000 barrels.

The sharp easterly dip of the pay sand in the South pool probably will increase the recovery materially, since wells in this pool have shown more pressure with a slower decline. Further, the withdrawal of gas apparently has not affected this field, and inasmuch as some leases have already shown a high recovery while not as yet depleted, it appears that an average of 15,000 barrels per acre is a fair estimate of the ultimate recovery for this pool.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 19, NO. 8 (AUGUST, 1935), PP. 1148-1161, 1 FIG.

SUBSURFACE DATA ON COVINGTON COUNTY, MISSISSIPPI[1]

WILLIAM O. GEORGE[2] AND HARRY X. BAY[3]
Laurel, Mississippi, and Urbana, Illinois

ABSTRACT

Petrographic analyses combined with micro-paleontology were used to obtain information of correlative value from about thirty core holes and three wells in Covington County, Mississippi. Formation contacts in some places are indicated by distinctive assemblages of heavy minerals where fossils do not occur. Foraminiferal faunas are zonally characteristic of the Gulf Coast area, except where variations are due to deep water or other conditions of environment. Not all of the divisions in the standard geologic column for Mississippi can be recognized in wells, and some of the formation contacts are necessarily arbitrary.

INTRODUCTION

Exploration of cut-over lands in southeastern Mississippi, for Eastman, Gardiner and Company, under the direction of A. C. Trowbridge[4] and Urban B. Hughes,[5] led to the drilling of about thirty core holes and three wells in Covington County (Fig. 1) during the years 1932 and 1933.

In preparation for the study of the cores and cuttings, approximately two hundred samples were collected from the outcropping formations in northeastern Mississippi. The examination[6] of these samples included the segregation and identification of heavy minerals, the mechanical classification of constituent materials, the percentage of acid-soluble material, and the study of fossils, particularly *Foraminifera*.

The writers are especially indebted to Mrs. F. B. Plummer for the identification of some of the Midway and Cretaceous fossils and for other valuable assistance.

[1] Published by permission of Eastman, Gardiner and Company, Laurel, Mississippi. Manuscript received, April 29, 1935.

[2] 606 Eighth Avenue, Laurel, Mississippi.

[3] Illinois Geological Survey.

[4] University of Iowa, Iowa City, Iowa.

[5] Consulting geologist, Laurel, Mississippi.

[6] Petrographic and lithologic determinations by Harry X. Bay and micropaleontologic data by William O. George.

The formations are described from the surface downward in the order in which they were encountered in the wells.

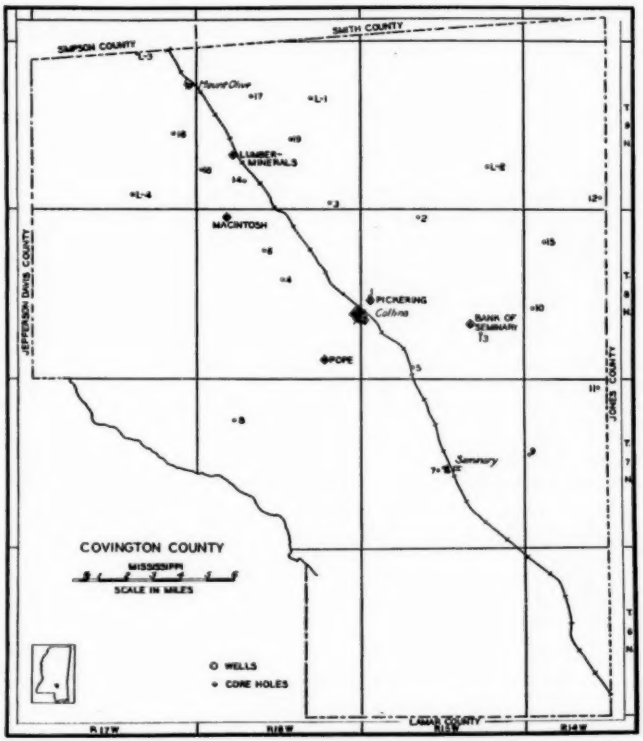

FIG. 1.—Covington County, Mississippi, showing location of core holes and wells.

CITRONELLE FORMATION

The Citronelle, which is the uppermost Pliocene formation, occurs as an unconformable blanket covering the truncated edges of the Hattiesburg clay and the Catahoula sandstone. It consists of poorly stratified red and yellow clays, sands, and gravel. Where the Hattiesburg clay is absent, it is difficult to distinguish the Citronelle from the underlying Catahoula sandstone, especially in well samples. In Covington County, the maximum thickness of this formation, which occurs on the tops of the hills, is about 250 feet. Locally, streams expose both of the underlying formations.

HATTIESBURG CLAY

The Hattiesburg clay is exposed in valleys and only in the southern part of the county. The contact with the Catahoula has been used by some geologists for detailed mapping of structural features. The formation as exposed in Covington County consists of blue clay which makes excellent mud for drilling purposes. It contains no marine fossils, and no petrographic analyses were made. An exposure occurs along the State highway about one mile east of Collins.

CATAHOULA SANDSTONE

Sand, gravel, variegated shales, and sandy, calcareous shales comprise the Catahoula sandstone. In well sections the upper limit of the formation is difficult to distinguish. The lower limit may be based on a sharp change in the heavy-mineral content of the sediments. The average thickness of the formation in Covington County is about 480 feet.

Several zones can be recognized in the Catahoula.[7] At about 140 feet below the top of the formation occurs a red-splotched, light gray, arenaceous shale which is 80–100 feet thick. Approximately 35 feet below this phase is a bed of very coarse sand and gravel which is about 60 feet thick. This was a source of difficulty to drillers because of caving and loss of returns. Two holes were abandoned at this horizon. Arenaceous shales and sands of variable thickness follow the caving formation. At the base of the non-marine phase of the Catahoula there is generally black lignitic clay or lignite 1–3 feet thick.

The lower part of the formation is represented by a marine phase about 70 feet thick. It is composed of dark gray-to-green shales and calcareous sands. Locally, the calcareous sand, just below the lignitic bed, becomes hard arenaceous limestone 2 or 3 feet thick. No ash beds were recognized in the Catahoula, but the green and black clay-

[7] Since this article was first written, the *Guidebook of the Eleventh Annual Field Trip of the Shreveport Geological Society in Southeast Mississippi* (1934) has been published. In this publication, the Catahoula formation is raised to the rank of a group containing the following divisions: "Catahoula," upper Chickasawhay member, lower Chickasawhay member, and Bucatunna member.

The writers are of the opinion that the calcareous beds at the base of the Catahoula in Covington County may be correlated with the upper Chickasawhay, and it is possible that thin beds of both the upper and lower Chickasawhay members are represented.

The upper part of the Byram marl as described in this paper bears some resemblance to the Bucatunna member, but definite correlation is yet to be proved. The presence of bentonitic or waxy clays is not sufficient evidence for correlation, since beds of this type are found both above and below the calcareous beds of the Catahoula. Also, in Smith County, Mississippi, bentonite has been found below strata which are believed to be Byram in age.

shales in the lower part of the formation have a waxy or bentonitic texture.

Foraminifera are fairly abundant in the marine zone. Most conspicuous are species of *Elphidium*, particularly *E. sagra* (d'Orbigny) and *E. incertum* (Williamson). Species of *Siphonina* and *Amphistegina* are common, with a doubtful and rare occurrence of *Heterostegina* sp. Fragments of bryozoans, ostracods, and fish teeth occur in the more calcareous portion of the zone.

A systematic search for distinctive mineral associations was made in Bank of Seminary No. 1 only. The Catahoula-Vicksburg contact is sharply marked by the heavy-mineral assemblages of the two formations. The basal Catahoula is characterized by the common occurrence of detrital tourmaline, garnet, and zircon, which are not found in the upper Vicksburg. The other heavy minerals of the Catahoula continue into the top of the Vicksburg.

The Catahoula lies unconformably on the Byram marl of the Vicksburg group.

VICKSBURG GROUP

Four divisions of the Vicksburg group are recognized in this area: (1) Byram marl, (2) Glendon limestone, (3) Marianna limestone, and (4) Red Bluff.

Byram marl.—The thickness of the Byram in Covington County varies from 300 to 485 feet. In general, the beds become thinner up dip or in a northeasterly direction. Locally, the unconformity is shown by the variety of material encountered in different wells at the Catahoula-Vicksburg contact.

The upper and greater portion of the Byram is composed of gray, green, and black clay-shale with silty partings and a few beds of siltstone with, here and there, a lense of sandstone. Calcareous shales or marls predominate in the lower portion, and in some places near the base hard limestones appear which can be distinguished from the Glendon only by paleontologic determinations. A solid core 20 feet long secured from core hole No. 15 was remarkably homogeneous in texture. The material was blue and gray when fresh and became nearly pure white after drying.

The section above the calcareous portion of the formation is similar to the sequence of beds above the calcareous portion of the Catahoula. Green and black lignitic shale and lignite occur just above the limestone or marl. The green shale is waxy and free from grit and has been called "bentonitic" shale. Since no attempt was made to identify the clay minerals, this classification is doubtful. Treatment with acid failed to produce activation.

Distinguishing heavy-mineral zones are absent. Probably the best guide fossil is *Asterigerina subacuta* Cushman which was abundant in most samples.

Glendon limestone.—Cooke[8] has given the rank of formation to three or four beds of hard white limestone, each 2 or 3 feet thick with interbedded gray marl and having a total thickness of about 20 feet. The large foraminifer, *Lepidocyclina mantelli* (Morton), is the best known fossil, but it is found also in the underlying Marianna.

Marianna limestone.—In Covington County, the Marianna limestone is about 40 feet thick and consists of uncemented fragments of corals and foraminifers which are poorly preserved. More than 95 per cent of the rock is soluble in hydrochloric acid. In spite of the local occurrence of hard beds in the Marianna, lithology is the best guide for recognition.

Red Bluff clay.—The Red Bluff clay is lithologically similar to the underlying Yazoo clay member of the Jackson formation and in some places the two can be distinguished by use of paleontology only. In Covington County the thickness ranges from 75 to 150 feet. It is composed of green, brown, and black clay and thin beds of sand. The sand in this part of the section suggests the beginning of the lateral transition from the Red Bluff to its probable equivalent, the Forrest Hill sand.

A few of the *Foraminifera* found in the Red Bluff occur also in the Yazoo clay. The evidence presented by Cooke[9] indicates that the Red Bluff is truly Oligocene in age. Howe[10] has published a list of Red Bluff *Foraminifera*, which shows a close relation to the Vicksburg group. However, according to Berry[11]

> . . . we find in the Forest Hill sand of Mississippi a flora of a predominantly Jackson facies and . . . the Red Bluff clay . . . contains elements partly common to the Jackson.

Paleobotany and lithology suggest that the time interval between the Oligocene and the Eocene was short.

Cores from the lower part of the Red Bluff in Lumber-Minerals No. 1 are as follows.

Feet	
804–816	Upper 1.5 feet, black shale alternating with thin streaks of fine-grained sand. Increasingly sandy toward base. Not calcareous. No *Foraminifera*
816–836	Black shale containing very little sand. Muscovite common in washed sample

[8] C. W. Cooke, "The Correlation of the Vicksburg Group," *U. S. Geol. Survey Prof. Paper 133* (1923), p. 3.

[9] C. W. Cooke, *op. cit.*, p. 2.

[10] H. V. Howe, *Jour. Paleon.*, Vol. II, No. 3 (1928), p. 173.

[11] E. W. Berry, *Amer. Jour. Sci.*, Vol. 213 (1927), p. 252

A convenient marker for the separation of the Red Bluff and Yazoo is an assemblage of heavy minerals which occurs at the base of the former. This suite of minerals includes an abundance of brown tourmaline, garnet, kyanite, zircon, ilmenite, and epidote. This association of detrital minerals was found in all wells penetrating this horizon.

Complete check lists, showing the relative number of each species, are needed for the paleontologic identification of the Red Bluff. The top of the formation is easily recognized by the character of the clay. The first appearance of *Textularia hockleyensis* Cushman and Applin was assumed to indicate the top of the Jackson formation.

JACKSON FORMATION

Only two members of the Jackson formation are recognized in Mississippi, the upper Yazoo clay and the lower Moodys Branch marl. The contact between the two members is gradational in Covington County. Their combined thickness is about 285 feet.

The Yazoo clay is composed of green, blue, and chocolate-colored shales in which many *Foraminifera* are well preserved. The Moodys Branch marl becomes increasingly sandy toward the base and contains small nodules of calcite and fragments of large fossils. There is a basal greensand, about 20 feet thick, which some geologists include with the Yegua. This basal zone is composed of fossiliferous, glauconitic, micaceous, argillaceous sand and thin beds of brown shale. A core at 1,377–83 feet from Bank of Seminary No. 1 was 30.65 per cent soluble in hydrochloric acid.

Characteristic *Foraminifera* of the Jackson include the well known *Textularia hockleyensis* Cushman and Applin, *Hantkenina alabamensis* Cushman, *Bulimina jacksonensis* Cushman, and *Bolivina jacksonensis* Cushman and Applin, all of which are fairly abundant. *Textularia dibollensis* Cushman and Applin occurs rarely and only in the lower part of the Jackson.

In the basal greensand, *Foraminifera* are small and poorly preserved. *Bulimina jacksonensis* Cushman and Applin, *Eponides jacksonensis* (Cushman and Applin), *Operculina* sp., and *Reussia* sp. are in this zone. The mineral composition of this sand is especially distinctive. In all three wells concretionary mineral grains were the outstanding lithologic feature. These grains were formed by the building up of concentric silica bandings about various mineral (both "heavy" and "light") nuclei. Associated heavy minerals are ilmenite, epidote, brown tourmaline, zircon, and pyrite. The mechanical composition of the greensand is essentially uniform in cores from all three wells.

CLAIBORNE GROUP

YEGUA FORMATION

The Yegua consists of 250–350 feet of greensand, dark greenish gray-to-brown lignitic shale, lignite, and arenaceous marl. The sandy parts are characterized by an abundance of siderite and glauconite, turritelloid gastropods, ostracods, fish teeth, and fragments of corals. *Haplophragmoides* sp. and *Eponides guayabalensis* Cole are fairly common in the Yegua samples. The fossils mentioned do not mark the upper or lower limits of the formation. The top of the Yegua is best indicated by the absence of the aforementioned Moodys Branch mineral assemblage; the base is shown by the first specimen of *Ceratobulimina eximia* (Rzehak), but this species does not occur everywhere at the top of the Lisbon.

LISBON FORMATION

"Wautubbee marl."—The uppermost part of the Lisbon formation, called "Wautubbee marl" by Lowe,[12] is 160–200 feet thick. Conspicuous in the "Wautubbee" are hard beds of finely micaceous, glauconitic, and siliceous limestone which contain spherical specimens of *Radiolaria*. These beds are strikingly similar to the hard limestone beds of the Tallahatta formation.

Significant *Foraminifera* are *Ceratobulimina eximia* (Rzehak), *Eponides guayabalensis* Cole, *Gyroidina soldani* (d'Orbigny), *Nonion planatum* Cushman and Thomas, *Siphonina claibornensis* Cushman, and *Haplophragmoides* sp.

In contrast to the barren zones of the Yegua, zircon, siderite, kyanite, epidote, and brown tourmaline are plentifully distributed in the upper part of the Lisbon, but these mineral species are not segregated so that they can be used for correlation.

Kosciusko sand member.—The Kosciusko sand member of the Lisbon formation comprises about 400 feet of thick beds of gray and brownish arenaceous shale, brown argillaceous sand, and some calcareous sand. Lignite occurs at some horizons.

The sand beds are generally barren of *Foraminifera*, and those found in the shales and calcareous beds are the common Lisbon forms.

The top of the member is distinguished by a group of heavy minerals that was identical in both the Lumber-Minerals No. 1 and Bank of Seminary No. 1 wells. Garnet, brown tourmaline, kyanite, pyrite, ilmenite, and epidote are the outstanding minerals. This is the first

[12] E. N. Lowe, "Mississippi, Its Geology, Geography, Soil, and Mineral Resources," *Mississippi Geol. Survey Bull. 14* (1919), p. 78.

occurrence of garnet in abundance showing below the top of the Jackson formation.

There is no dependable marker for the base of the Kosciusko.

Winona member.—The Winona member has an estimated thickness of 300 feet. It consists of brown sand, brown sandy shale, and brown clay-shale. At intervals there are beds of glauconitic sand containing fragments of gastropods, ornate ostracods, and a few *Foraminifera* typical of the Lisbon. Outstanding mineral zones are lacking except for an abundance of chamosite and siderite in the lower part of the member.

TALLAHATTA FORMATION

The Tallahatta formation, which is about 280 feet thick in Covington County, is essentially calcareous. The upper part consists of light greenish gray, glauconitic, micaceous, argillaceous and arenaceous limestone and extremely calcareous siltstone. The top of the formation is hard and is easily recognized by the driller. In the lower part, the limestone is interbedded with greenish gray shale.

Foraminifera and spherical *Radiolaria* are abundant but difficult to separate from the matrix. Large specimens of robuline species are common. Specimens of *Ceratobulimina eximia* (Rzehak) and *Eponides guayabalensis* Cole were not found.

The following analysis of a core of light greenish gray, calcareous, micaceous, and glauconitic siltstone at 2,640 feet in Bank of Seminary No. 1 is typical of the Tallahatta.

Soluble in hydrochloric acid, 51.6 per cent
Insoluble residue
  Maximum grade, 1/64 mm., 43 per cent
  Secondary maximum, 1/32–1/64 mm., 19 per cent
  Grade range, 1/2–1/64 mm.
Heavy mineral content
  Principal heavy minerals: chamosite, pyrite, aragonite
  Accessory heavy minerals: epidote, ilmenite

WILCOX GROUP

Although the Wilcox group has been divided into the Hatchetigbee, Bashi, Holly Springs, and Ackerman formations, these divisions are not recognizable, nor is there a satisfactory horizon at which the Wilcox can be separated from the Midway. With the position of the base of the group uncertain, the thickness assigned to the Wilcox in Covington County is 950 feet.

The first brown shale or lignite below the Tallahatta has been accepted by some geologists as the top of the Wilcox in Mississippi, but this criterion loses value where limestone beds occur below it. A solution to the problem presented itself in the appearance of an abun-

dance of garnet within the range of expectancy. Between the top of the Wilcox and the upper part of the Winona sand member of the Lisbon formation no other horizon contains much garnet. This zone can hardly be regarded as an arbitrary basis for the division of the section. Samples were collected from outcrops in Clarke County, Alabama, where a slight disconformity between the Wilcox and Claiborne is evident at the surface. The Wilcox samples were characterized by heavy concentrations of garnet. The zone is clearly defined in Lumber-Minerals No. 1, Bank of Seminary No. 1, and in several wells outside of Covington County.

The Wilcox[13] strata comprise a heterogeneous lithologic composite which includes thick beds of brown, gray, and green shales, arenaceous shales, argillaceous sands, and thin hard limestone beds at irregular intervals. Lignite is common throughout the Wilcox and is particularly abundant in the upper and middle strata.

Except the garnet zone at the top, mineral zones in the Wilcox lack distinction. The lower part of the group contains a diversified assemblage of heavy minerals of doubtful correlative value.

Foraminifera are not abundant in the Wilcox in this area, but a few of the forms figured by Cushman and Ponton[14] were found about 70 feet below the garnet zone. They occur more commonly 500 or 600 feet below this zone. *Globorotalia wilcoxensis* Cushman and Ponton, *Pulvinulinella exigua* (H. B. Brady), *Pseudouvigerina wilcoxensis* Cushman and Ponton, and *Epistominoides wilcoxensis* (Cushman and Ponton) occur in the more calcareous parts of the group, the first mentioned being most conspicuous.

MIDWAY GROUP

On the assumption that the first appearance of *Ammobaculites midwayensis* Plummer marks the top of the Midway, the total thickness of the group in Bank of Seminary No. 1 is 2,562 feet. However, experience with other wells in Mississippi has proved that this species is not a dependable guide, and the thickness as given, therefore, is questionable. In many places this well known Midway form is associated with a species of *Haplophragmoides*. Both are deep-water forms and evidently sensitive to environment.

Formational divisions of the Midway could not be distinguished in the samples from Bank of Seminary No. 1, but it was noted that

[13] The full thickness of the Wilcox was penetrated in Bank of Seminary No. 1 only, and data below the Wilcox were obtained from this well alone.

[14] J. A. Cushman and Gerald Ponton, "An Eocene Foraminiferal Fauna of Wilcox Age from Alabama," *Contr. Cushman Lab. Foram. Res.*, Vol. 8 (September, 1932), Pt. 3.

the lower 500 feet of black shale was similar to the material of the Porters Creek formation. The upper part of the group is composed of green, gray, and brown sandy shales and sands. There are also thin beds of hard calcareous shales and siderite. It should be remembered that an isolated concretion would be logged as thin limestone and that concretions occur commonly in the Midway. Lignite occurs mixed with the other sediments throughout the group. The sand beds are both indurated and friable and grade from fine to coarse in texture. Most calcareous zones are glauconitic, as are some of the sands.

Distinctive associations of heavy minerals were not found. At about 400 feet below the *Ammobaculites midwayensis* Plummer zone there was a noteworthy occurrence of small siliceous pellets. These quartzitic aggregates, which have an average diameter of about 3 millimeters, occupied about one-fourth of the volume of the washed sample.

The lower black shale section is characterized by lithologic homogeneity. It is black fissile clay-shale. Mechanical analyses on eleven cores showed that in each sample more than 70 per cent of the constituent grains were less than 1/64 millimeter in diameter. Thin hard limestone and siderite beds (concretions?) break the continuity of the shale section at irregular intervals. The following analysis of black, calcareous, micaceous shale from a core at 5,955–58 feet in Bank of Seminary No. 1 is typical.

Soluble in hydrochloric acid, 11.6 per cent
Insoluble residue
  Maximum grade, 1/64 mm., 74 per cent
  Secondary maximum, 1/32–1/64 mm., 16 per cent
  Grade range, 1/16–1/64 mm.
Heavy-mineral content
  Principal heavy minerals: siderite, pyrite
  Accessory heavy minerals: blue tourmaline, rutile, biotite, ilmenite

Midway *Foraminifera* are closely related to those so clearly described by Mrs. Plummer[15] from the Midway of Texas. It is only in the lower black shale, however, that these species are well represented. In the 2,000 feet of section above the black shale, no single sample contained more than six species and many of these were distorted, evidently by pressure. The following were observed: *Lenticulina midwayensis* (Plummer), *Loxostoma applinae* (Plummer), *Nodosaria affinis* d'Orbigny, *Siphonina prima* Plummer, *"Cristellaria" longiforma* Plummer, *Globigerina triloculinoides* Plummer, *G. compressa* Plummer, and *Cibicides alleni* (Plummer). Some of the cores from the black

[15] Helen Jeanne Plummer, "The Foraminifera of the Midway Formation," *Univ. Texas Bull. 2644* (1926).

shale contained no fossils at all; others yielded a fairly large number of *Foraminifera*.

EOCENE-CRETACEOUS TRANSITION BEDS

For lack of more positive evidence, the section between 6,157 feet and 6,395 feet is regarded as indicating a transition between the Eocene and the Cretaceous. This part of the section is not exposed in Mississippi or Alabama. The upper part of it appears to be a continuation of the black shales; the lower 35 feet is hard limestone which appears abruptly at 6,363 feet. The limestone may be the equivalent of the basal Midway Clayton limestone but the fauna is typical of neither Midway nor Selma.

The following species of *Foraminifera* were found in six cores from the transition beds: *Ammodiscus incertus* (d'Orbigny), *Anomalina rubignosa* Cushman, *Bulimina* sp., *Cornuspira "cretacea," Globigerina belli* White, *G. triloculinoides* Plummer, *Glomospira gordialis* (Jones and Parker), *Gyroidina nitida* (Reuss), *Gümbelina* sp. (single specimen, very finely striated), *Gyroidina retusa*? Cushman, *Haplophragmoides excavata* Cushman and Waters, *Marginulina decorata* (Reuss), *Nodellum velascoensis* (Cushman), *Nodosaria monile*? v. Hagenow, *Pelospina complanata* Franke, *Pseudoglandulina*? sp., *Rzehakina epigona* (Rzehak) var. *lata* Cushman and Jarvis, *Spiroplectammina dentata* (Alth), *Spiroplectoides clotho* (Gryzbowski), *Textularia concinna* Reuss, and *Trochammina globigeriniformis*? (Jones and Parker).

The following analysis was made of a core taken at 6,363–65 feet. The sample was dark gray, indurated, argillaceous limestone, alternating with bluish gray calcareous shale.

Soluble in hydrochloric acid, 65 per cent
Insoluble residue
  Maximum grade, 1/64 mm., 62 per cent
  Secondary maximum, 1/8–1/16 mm., 14 per cent
  Grade range, 1/4–1/64 mm.
  80 per cent in shale grades
Heavy-mineral content
  Principal heavy minerals: epidote (especially abundant), chlorite, pyrite, garnet, zircon
  Accessory heavy minerals: green hornblende, brown tourmaline, biotite, rutile, and staurolite.

In this sample were *Dorthia*? sp., *Bolivina primatumida* White, and *Cibicides alleni* (Plummer). The genera *Globotruncana* and *Gümbelina* were not represented.

CRETACEOUS SERIES

SELMA FORMATION

A calcareous fauna, characteristic of the Selma formation, appeared at 6,390 feet. The core contained many species of *Globotruncana* and *Gümbelina*.

The upper part of the Selma consists of indurated, light-to-dark gray, more or less argilaceous limestone containing 60–80 per cent calcium carbonate. The middle[16] part is nearly pure limestone. Most of the cores were dark blue, gray, or black. At about 7,500 feet the samples became increasingly glauconitic and micaceous.

TABLE I

SUMMARY OF LOG OF EASTMAN, GARDINER AND COMPANY'S BANK OF SEMINARY NO. 1
(Elevation, 426 Feet)

	Formation		*Depth to Top of Formation (Feet)*	*Lithologic Characteristics*	*Important Mineral Zones*	*Significant Foraminifera*
PLIOCENE	Citronelle formation		0	Red and yellow clay, sand, and gravel		
MIOCENE	Catahoula formation		90	Variegated shales, sand, gravel, sandy limestone, and marl	Brown tourmaline, garnet, zircon at base	*Elphidium sagra, E. incertum, Amphistegina* sp. *Foraminifera* at base only
OLIGOCENE	Vicksburg group	Byram (?)	572	Upper green shales and marl	Pyritic and sideritic. Garnet between 760 and 800 feet	*Asterigerina subacuta*
		Vicksburg limestone	942	Greenish gray marl, pure and sandy limestone. Green shale	Pyritic and sideritic	*Lepidocyclina mantelli*
		Red Bluff	1,002	Brown calcareous shale; marly beds	Kyanite, ilmenite, epidote at top; brown tourmaline, garnet, kyanite, zircon, ilmenite, epidote at base	*Bulimina sculptilis, B. jacksonensis*
EOCENE	Jackson formation		1,117	Gray and green shales	Garnet, kyanite, ilmenite, epidote in upper 30 feet	*Textularia hockleyensis, Hantkenina alabamensis, Bolivina jacksonensis*
	Claiborne group	Yegua formation	1,378	Micaceous greensand, lignitic shales, sandy marl	Concretionary grains, epidote, zircon, kyanite, brown tourmaline at top. Lower part barren	*Haplophragmoides* sp., *Eponides guayabalensis*
		Lisbon formation	1,640	Green sandy marl, brown shale, glauconitic sand. "Wautubbee marl" member	Kyanite, ilmenite, epidote at top	*Ceratobulimina eximia, Gyroidina soldani, Siphonina claibornensis*
			1,808	Gray and brown shale and sand; partly lignitic. Kosciusko member	Garnet, kyanite, brown tourmaline, zircon, ilmenite at top. Garnet throughout	Rare
			2,107	Brown sand and shale, partly glauconitic. Winona sand member	Chamosite common	*Ceratobulimina eximia, Gyroidina soldani*
		Tallahatta formation	2,395	Greenish gray sandy limestone; siltstone; shaly near base	Zircon and rutile, 2,608–15 feet	Large robuline species

[16] No petrographic studies were made below 6,700 feet.

	Formation	Depth to Top of Formation (Feet)	Lithologic Characteristics	Important Mineral Zones	Significant Foraminifera
EOCENE	Wilcox group	2,640	Green and gray sand, shale; thin limestones; lignitic in upper part	Garnet at top and throughout. Chloritic zones	*Globorotalia wilcoxensis*, *"Sarcenaria" wilcoxensis*, *Pulvinulinella exigua*, *Pseudouvigerina wilcoxensis*
	Midway group	3,594	Green, gray, and brown shales and sands, partly lignitic	Zircon below 4,300. Tremolite, 4,720–80, also 5,360–90. Blue tourmaline, 4,800–10, also 5,387–95. Green tourmaline, 4,850–5,030. Rutile, 4,600–5,100 feet	*Ammobaculites midwayensis*, *Lenticulina midwayensis*, *Loxostoma applinae*, *"Cristellaria" longiforma*
		(?)			
		5,663	Black fissile shale. Porters creek formation	Pyritic, sideritic. Zircon in upper 40 feet	Calcareous Midway fauna
CRETACEOUS (?)	Eocene-Cretaceous transition	6,157	Dark gray, argillaceous limestone. Indurated	Epidote, siderite, and pyrite. Chloritic. Garnet in lower 30 feet	*Ammodiscus incertus*, *Nodellum velascoensis*, *Globogerina belli*, *Pelosina complanata*
CRETACEOUS	Selma chalk	6,395	Light and dark gray argillaceous limestone	Chlorite and garnet in upper 30 feet. Chlorite, 6,510–6,670 feet	*Gümbelina* sp., *Globorotalia* sp.
	Eutaw formation	7,946	Micaceous, glauconitic sand	Mineral analyses discontinued at 6,707 feet	No fossils

EUTAW FORMATION

No *Foraminifera* were found in the Eutaw, and, since the lithologic change from Selma to Eutaw is gradational, the contact between the two formations is more or less arbitrary. In most places, the first appearance of micaceous and glauconitic sand marks the top of the Eutaw. In this well a small core obtained at a depth of 7,946 feet contained dark gray shale and aggregates of sand composed of quartz, pyrite, muscovite, and glauconite. No fossils were found at this depth. The well was abandoned at 8,002 feet without penetrating the full thickness of the Eutaw.

CONCLUSIONS

The combined use of sedimentary petrography and micro-paleontology has produced useful and practical results in the classification of well samples in Mississippi.

Certain heavy-mineral zones were found to persist for a distance of 75 miles.

Mechanical analyses proved to be of little value for correlation but such results may be used in the study of oil sands and the interpretation of geologic history.

The discovery of deep-water *Foraminifera* in the Eocene-Cretaceous transition beds suggests that during this interim Covington County was not far from an area of continuous deposition.

TABLE II

GUIDE TO FORMATION NAMES IN MISSISSIPPI*

	Texas		*Louisiana*	*Mississippi*	*Alabama*
PLIOCENE	Lagarto clay Citronelle formation Lapara sand		Citronelle formation	Citronelle formation	Citronelle formation
MIOCENE	Oakville sandstone Pascagoula clay Catahoula sandstone		Pascagoula clay Catahoula sandstone	Pascagoula clay Catahoula sandstone	Pascagoula clay Catahoula sandstone
OLIGOCENE	Frio Vicksburg		Vicksburg limestone	Byram marl Glendon limestone with Mint Springs member Marianna Forest Hill sand Red Bluff clay	Byram marl Glendon formation Marianna limestone
EOCENE	Whitsett McElroy Caddell		Jackson formation	Jackson formation Yazoo clay member Cocoa sand Moodys Branch marl member	Jackson formation Ocala limestone
	Claiborne group	Yegua formation Cook Mountain formation Mount Selman formation	Yegua formation Cook Mountain formation St. Maurice formation Cane River formation	Yegua formation Lisbon formation "Wautubbee marl" member Kosciusko member Winona sandstone Tallahatta formation	Gosport sand Lisbon formation Tallahatta formation
	Wilcox group	Bigford formation Carrizo formation Indio formation	Wilcox formation	Grenada formation Bashi formation Holly Springs sand overlapped Ackerman formation	Hatchetigbee formation Bashi formation Tuscahoma sand "Pseudobuhrstone" *Ostrea thirsae* zone overlapped
	Midway group	Midway formation	Midway formation	Porters Creek clay with Tippah sandstone member Clayton formation	Naheola formation Sucarnochee clay Clayton formation
UPPER CRETACEOUS	Navarro Taylor Austin		Navarro Taylor Austin	Ripley and Selma Eutaw Tuscaloosa	Ripley and Selma Eutaw Tuscaloosa

* Names in common usage, compiled from various reports. Not offered as correlations.

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NOTES ON THE VICKSBURG GROUP[1]

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ABSTRACT

The Forest Hill sand is proved to be of Vicksburg (Oligocene) age because it overlies the Red Bluff clay where the two interwedge. The Salt Mountain limestone, until recently placed at the top of the Vicksburg group, contains *Discocyclina*, and is Lower Eocene; according to Blanpied, it lies between the Nanafalia formation and the Tuscahoma sand of the Wilcox group. The Chickasawhay marl and the Bucatunna clay are accepted as members of the Byram marl. The chert beds of southeastern Alabama, Georgia, South Carolina, and Florida, formerly classed as Glendon, are named the Flint River formation and are tentatively correlated with the Chickasawhay member of the Byram marl. The Catahoula sandstone appears to be older than the Tampa limestone.

In 1918, the writer published a short paper on the "Correlation of the Deposits of Jackson and Vicksburg Ages in Mississippi and Alabama,"[3] in which was proposed a classification of the Vicksburg group. Additional data on the same subject were presented in "The Byram Calcareous Marl of Mississippi"[4] and in "The Correlation of the Vicksburg Group."[5] Some details of the stratigraphy of the Vicksburg group in Alabama and Florida were later presented in the "Geology of Alabama"[6] and in the "Geology of Florida."[7] Since these reports were written, much work has been done by others in Mississippi and Alabama, some results of which were made public in October, 1934, in the guidebook prepared for the eleventh annual field trip of the Shreveport Geological Society by a committee consisting of B. W. Blanpied (chairman), Albert E. Oldham, and C. I. Alexander, with the collaboration of several other geologists.

[1] Manuscript received, March 22, 1935. Published by permission of the director of the United States Geological Survey.

[2] United States Geological Survey.

[3] C. W. Cooke, *Washington Acad. Sci. Jour.*, Vol. 8 (1918), pp. 186–98.

[4] *Ibid., U. S. Geol. Survey Prof. Paper 129* (1922), pp. 79–85.

[5] *Ibid., Prof. Paper 133* (1923), pp. 1–9.

[6] G. I. Adams, Charles Butts, L. W. Stephenson, and Wythe Cooke, *Alabama Geol. Survey Spec. Rept. 14* (1926), pp. 279–94.

[7] C. W. Cooke and Stuart Mossom, *Florida Geol. Survey Twentieth Ann. Rept.* (1929), pp. 61–76.

RED BLUFF CLAY AND FOREST HILL SAND

One advance in knowledge concerns the stratigraphic relations of the Red Bluff clay and the Forest Hill sand, which lie at the base of the Vicksburg group in Mississippi and western Alabama. The writer's paper of 1918 contained the statement that

> as the Red Bluff formation has not been traced west of Wayne County [Mississippi], its relations to the Forest Hill sand are conjectural, but it is believed that the two were approximately contemporaneous in origin and that the Red Bluff clay represents the marine equivalent [in the east] of the exceedingly shallow-water deposits of the Forest Hill sand in the Mississippi Embayment.[8]

This belief appears to have been corroborated, but it has been further learned that in the transition area both formations are present in the form of wedges, with the Forest Hill wedge above the Red Bluff.[9] This discovery definitely proves that the Forest Hill sand is of Vicksburg age—not Jackson as some geologists have supposed.

AGE OF SALT MOUNTAIN LIMESTONE

Another discovery concerns the age of the Salt Mountain limestone of Alabama. The name "Salt Mountain limestone" was first used in 1891 by Langdon[10] as follows.

> The uppermost or Salt Mountain division of this Vicksburg group is seen nowhere east of the typical locality, and so does not enter into the geological features of this section of Alabama. As a matter of fact, the characters of the Salt Mountain limestone—i.e., corals and spines of echinoids—point rather to its being an atoll built up in Tertiary seas than any extensive deposit justifying the constitution of a group.

Most other authors have referred to the rock at Salt Mountain as the "coral limestone" and have placed it at the top of the Vicksburg group. In 1918, the writer accepted this correlation, but said:[11]

> The Salt Mountain section, which has been considerably disturbed by folding and faulting, deserves more critical study than it has yet received.

Such critical study has since been given by B. W. Blanpied, who, from study of well logs, finds that the Salt Mountain limestone occupies a place within the Wilcox group between the Tuscahoma sand and the Nanafalia formation.[12] It was upthrust to its present position

[8] C. W. Cooke, *Washington Acad. Sci. Jour.*, Vol. 8 (1918), p. 193.

[9] Roy T. Hazzard and B. W. Blanpied, *Guidebook of the Eleventh Annual Field Trip of the Shreveport Geological Society into Southeast Mississippi* (1934), p. 9.

[10] D. W. Langdon, *Bull. Geol. Soc. America*, Vol. 2 (1891), p. 599.

[11] C. W. Cooke, *Washington Acad. Sci. Jour.*, Vol. 8 (1918), p. 197.

[12] *Guidebook of the Ninth Annual Field Trip of the Shreveport Geological Society* (1932), p. 9 and correlation table.

adjacent to the Vicksburg group by the Jackson fault. The determination of its age as Eocene is corroborated by the presence of an undescribed species of *Discocyclina* (*Discocyclina*)[13] in large numbers.

Salt Mountain is the type locality of *Stylophora ponderosa* Vaughan and *Actinacis alabamensis* (Vaughan), two corals that have been reported also from Antigua and near Bainbridge, Georgia, respectively.[14] If these corals really came from the Eocene Salt Mountain limestone, it is likely that the later identifications are wrong; but, as Oligocene Glendon limestone and Byram marl are exposed near by, it is possible that they came instead from the Oligocene. The disagreement as to the age of the rocks near Salt Mountain is due to the fact that two similar limestones of different ages are faulted into juxtaposition.

BYRAM MARL

The *Guidebook of the Eleventh Annual Field Trip of the Shreveport Geological Society into Southeast Mississippi* directs attention to certain deposits in Wayne County, Mississippi, that have heretofore been regarded as the upper part of the Byram marl of Vicksburg (Oligocene) age. It states that these deposits are separated from the underlying beds of typical Byram age by an unconformity and that they transgress across older formations of the Vicksburg group. It recognizes three divisions among these supposed post-Byram deposits. It proposes the name Bucatunna member for the sand and clay that compose the lowest division and designates the limestone and marl that compose the other two as lower and upper Chickasawhay members. All three divisions were referred to the Catahoula "group." The contributors to the *Guidebook* were not in agreement as to the ages of the deposits, some contending that all three divisons are Miocene and others that only the uppermost is Miocene, the other two being Oligocene.

The writer's acquaintance with these deposits and with deposits of the same age in Alabama began in 1913, before the present classification of the Vicksburg group had been proposed. In 1915, he noted at the mouth of Limestone Creek in Wayne County, Mississippi, discontinuous exposures of yellowish marl and limestone, separated by concealed intervals possibly underlain by clay, extending to a height of 70 feet above what is now called the Glendon limestone and containing impressions of *Anadara lesueuri* (Dall). He supposed that all of these exposures represented only one formation, of which the

[13] Identified by T. W. Vaughan and L. G. Henbest, independently.

[14] T. W. Vaughan, *U. S. Nat. Mus. Bull. 193* (1919), p. 206.

deposits at Byram and Vicksburg that are now called Byram marl formed a part. This is the basis of his statement in 1918 that "incomplete exposures indicate a thickness of at least 70 feet" for the Byram marl on Chickasawhay River.[15] These beds were therefore included in the Byram marl in the original description of that formation. The writers of the *Guidebook* assign 26 feet of this 70-foot interval to the Bucatunna member and about 20 feet to the lower Chickasawhay member.

BUCATUNNA CLAY MEMBER OF BYRAM MARL

The name "Bucatunna member of the Catahoula group" is applied by the authors of the *Guidebook* to "a sequence of bentonitic clays, bentonite, and cross-bedded sands which rest upon the rocks of the Vicksburg group with distinct unconformity."[16] The typical exposures extend along Bucatunna Creek from a point in Sec. 6, T. 8 N., R. 5 W., 0.5 mile above Dyess Bridge, where the Bucatunna formation overlies the Byram marl, to the bend in the creek about 800 feet northeast of the center of Sec. 8, T. 8 N., R. 5 W., where it is in contact with the overlying Chickasawhay limestone.[17] According to the writer's notes of May 29, 1916, about 8 feet of hackly brownish gray clay resembling fuller's earth is exposed on the east bank of Bucatunna Creek 100 yards below Dyess Bridge. The thickness of the member near Chickasawhay River is 26 feet. The statement that the Bucatunna clay lies unconformably on the Byram marl and overlaps beyond it across the Glendon and Marianna limestones[18] is open to question. It is based on the assumptions that the deposits of clay and bentonite found on these formations at several places in Wayne and Jasper counties are of the same age and that all occupy their original positions. So far as the writer is aware, these assumptions have not been proved. Bentonite and clay resembling bentonite occur at several horizons in Mississippi, including the Chickasawhay marl member, which overlies the Bucatunna clay. Moreover, clay of this kind flows readily under pressure. Some of the clay that now lies unconformably on the Byram, Glendon, or Marianna, may have been squeezed out of an outcrop of the Bucatunna or of a higher formation and may have crept down the slope to its present position. This

[15] C. W. Cooke, "Correlation of the Deposits of Jackson and Vicksburg Ages in Mississippi and Alabama," *Washington Acad. Sci. Jour.*, Vol. 8 (1918), p. 196.

[16] *Guidebook of the Eleventh Annual Field Trip of the Shreveport Geological Society into Southeast Mississippi* (1934), p. 13.

[17] *Ibid.*

[18] *Ibid.*

method of accumulation would account for the great variability in thickness of the clay and also for its apparent accumulation across a ridge of Byram marl as reported in the *Guidebook*.[19]

The removal of the Bucatunna clay from the Vicksburg group is not demanded by its lithologic character, for it is very similar to parts of the Red Bluff clay and the Forest Hill sand. The fauna of the Bucatunna in Wayne County, Mississippi, is unknown, but it is not improbable that the clay will be proved to be contemporaneous with the 20 feet of dark gray clay exposed along Jay Branch in Monroe County, Alabama, which contains many Byram mollusks.[20] The 25 feet of fine gray laminated sand that conformably overlies the typical Byram marl at Vicksburg, which sand the writer doubtfully referred to the Catahoula sandstone in 1922,[21] may be equivalent to the Bucatunna clay member. The grouping of the Bucatunna clay with the Catahoula sandstone seems entirely unjustified. Until contradictory evidence is presented, the Bucatunna clay should be treated as a member of the Byram marl of the Vicksburg group.

CHICKASAWHAY MARL MEMBER OF BYRAM MARL

The Chickasawhay marl member of the Byram marl was named from Chickasawhay River on and near which it is characteristically exposed in the vicinity of Waynesboro, Mississippi. The member consists chiefly of impure limestone and marl.

The lower half of the member is described in the following section, which was measured in 1921 on the road to Shubuta in Sec. 24, T. 9 N., R. 7 W., about 4 miles north of Waynesboro.

SECTION OF BYRAM MARL NORTH OF LIMESTONE CHURCH

	Feet
Chickasawhay marl member	
5. Brown plastic clay, mostly concealed by red surficial sand	
4. Very calcareous creamy yellow marl or impure limestone containing *Turritella* cf. *ceibana*, *Anadara lesueuri*?, *Ostrea vicksburgensis*, *Pecten* 4 species, *Cardium*, *Miltha*?, *Chione*, *Anomia*, *Teredo circula*, *Echinolampas aldrichi*, *Lepidocyclina*, etc. (station 1/53)	11
3. Very plastic brown or gray clay	6
2. Creamy yellow calcareous clay or marl with nodular ledges of marlstone at top and near bottom; upper part contains many irregular small white concretions and large nodular boulder-like concretions of marlstone; *Ostrea vicksburgensis*, *Pecten* sp., and *Anomia* sp. at top	9
Bucatunna clay member	
1. Fine gray laminated sticky sand with concretionary masses resembling fucoids in upper part	23

[19] *Ibid.*, p. 14.

[20] C. W. Cooke in "Geology of Alabama," pp. 290–91.

[21] C. W. Cooke, "The Byram Calcareous Marl of Mississippi," *U. S. Geol. Survey Prof. Paper 129* (1922), p. 81.

The upper part of the member is exposed at several places on Chickasawhay River that the writer has not visited. The *Guidebook* calls attention to three localities (*CV*, *CX*, and *CY*) on the west bank in Sec. 10, T. 8 N., R. 7 W., west of Waynesboro, where marl containing *Lepidocyclina*, *Teredo* tubes, and *Echinolampas aldrichi*, and evidently representing very nearly the same horizon as bed 4 of the section north of Limestone Church, forms the base of the exposure. The section at locality *CX*, adapted from the *Guidebook*,[22] is as follows.

SECTION OF CHICKASAWHAY MARL ON WEST BANK OF CHICKASAWHAY RIVER 0.1 MILE SOUTHWEST OF CENTER OF SEC. 10, T. 8 N., R. 7 W., WAYNE COUNTY, MISSISSIPPI

	Feet
9. Fossiliferous claystone and blue shale	5–7
8. Claystone with large oysters	2
7. Ledge of hard calcareous claystone	1.5
6. Fossiliferous blue shale	0.5
5. Ledge of hard claystone	1
4. Hard calcareous fossiliferous claystone	2
3. Fossiliferous blue clay	10
2. Hard fossiliferous marly limestone	0.5
1. Gray fossiliferous glauconitic marl	1.5

The oyster bed is reported also at locality *CZ*, on the east bank of Chickasawhay River at the SE. Cor., SW. ¼, Sec. 10, T. 8 N., R. 7 W.[23] It occurs also in the northwest part of Sec. 25, T. 8 N., R. 7 W., about 200 yards above the bridge 2.5 miles south of Waynesboro, where the writer measured the following section in 1913.

SECTION ON SOUTH BANK OF CHICKASAWHAY RIVER ABOVE HIGHWAY BRIDGE 2.5 MILES SOUTH OF WAYNESBORO

	Feet
Pleistocene	
8. Sandy clay and silt	15
Oligocene (?); Catahoula sandstone (?)	
7. Green and brown clay containing nodules of pyrite	7
Oligocene; Byram marl (Chickasawhay marl member)	
6. Soft green marl composed chiefly of sand; many echinoid spines at base; hard and red at top	3.5
5. Hard white sandy marl	0.5
4. Green sandy marl containing many echinoid spines; a few oysters near bottom	1.25
3. Bed composed almost entirely of large oysters	0.5
2. Soft green marl	1
1. Hard green marlstone or limestone; to water level	1.5

The writer revisited this place on April 4, 1934, and obtained (station 13,388) *Turritella* sp., *Ostrea vicksburgensis*, *Ostrea* sp., *Macoma* sp., and small fragments of a regular echinoid that seems to be

[22] *Op. cit.*, p. 47.

[23] *Ibid.*, p. 48.

Coelopleurus aldrichi Clark, a species known elsewhere only from Perdue Hill, Alabama, where it probably occurs in the Chickasawhay marl.

From these and other detailed sections has been compiled the following generalized section, which is believed to show the complete thickness of the Byram marl in the vicinity of Waynesboro, Mississippi.

	Feet
Byram marl	
Chickasawhay marl member	
Alternating beds of hard and soft sandy marl containing *Coelopleurus aldrichi* Clark? in upper part and large oysters in middle	10
Blue or brown clay	10
Yellow marl or limestone containing *Echinolampas aldrichi*, *Lepidocyclina favosa* Cushman, *L. undosa* Cushman, *Teredo circula* Aldrich, *Chione* sp., *Anadara lesueuri* Dall, and many other fossils	11
Plastic brown or gray clay	6
Yellow clayey marl with ledges of nodular marlstone; small irregular white concretions in upper part; *Ostrea vicksburgensis* Conrad and other fossils	9
Bucatunna clay member	
Clay exposed, according to *Guidebook*, in a gully near State quarry at mouth of Limestone Creek	26
Typical part of Byram marl	
Blue, gray, or yellow marl and at least one 2-foot ledge of limestone; exposed at Trestle 85-A, 0.75 mile south of Limestone Creek, and on Chickasawhay River at Woodwards, where it contains (station 6,648) *Lepidocyclina supera* (Conrad), *Dentalium mississippiense* Conrad, *Anadara lesueuri* (Dall), *Ostrea vicksburgensis* Conrad, *Pecten poulsoni* Morton, 25 species of *Bryozoa* and many small *Foraminifera;* thickness about	7
Glendon limestone	
Hard and soft white limestone exposed at State quarry at mouth of Limestone Creek, where it contains (station 13,384) *Clypeaster rogersi* (Morton), *Lepidocyclina mantelli* (Morton), *Ostrea vicksburgensis* Conrad, *Pecten poulsoni* Morton, *P. analipes* Morton, *P.* n. sp., *Pitaria imitabilis* (Conrad), and other fossils	6
Marianna limestone	
Soft white chimney rock containing *Lepidocyclina mantelli* (Morton), and *Pecten poulsoni* Morton; exposed to low-water mark on Chickasawhay River at mouth of Limestone Creek; thickness at least	23

The Chickasawhay marl member contains a large marine fauna, but many of the shells have been dissolved away, leaving only molds. Of the larger fossils the oysters, pectens, anomias, lepidocyclinas, and echinoids generally retain their shelly structure, and the tubes of teredos are also preserved. These tubes, to which Aldrich applied the name *Teredo circula*, are common and widespread at this horizon but can not be relied on for distant correlations. The large echinoid *Echinolampas aldrichi* Twitchell appears to be restricted to the Chickasawhay member.

The fauna of the Chickasawhay marl member differs conspicuously from that of the typical (basal) part of the Byram in the apparent absence of *Pecten poulsoni* Morton, a species very abundant at Byram and also in the Glendon and Marianna limestones. Its place is taken by several other species of *Pecten*. *Lepidocyclina supera* (Conrad), the common species at Byram and Vicksburg, if present in the Chickasawhay member, is not as common as the species listed by M. A. Hanna and Donald Gravell[24] as *Lepidocyclina undosa* Cushman and *L. favosa* Cushman. Molds of *Anadara lesueuri* Dall, which is very abundant in the typical Byram marl, are fairly abundant in the Chickasawhay marl member, and several other species, too poorly preserved for positive identification, appear to represent Vicksburg species. There are also many impressions of one or two species of *Chione* that very closely resemble *Chione bainbridgensis* Dall from the supposed Glendon cherts of Georgia (herein called Flint River formation) and *Chione spenceri* Cooke from Antigua.

Because of these differences in fauna between the Chickasawhay member and the typical part of the Byram, one might be justified, if starting with a clean slate, in assigning formational rank to the Chickasawhay marl; but the Chickasawhay member forms part of the Byram marl as originally defined and was described as the Byram marl in what is likely to remain the standard reference book on the geology of Alabama[25] for years to come. The writer was fully aware, when writing the description of the Byram marl for that report, that most of the outcrops referred to the Byram were similar to the formation as exposed in Wayne County, Mississippi, rather than to the typical Byram of Byram and Vicksburg. Moreover, the differences in fauna may not be as great as they appear, for several additional Vicksburg species have been identified in the Chickasawhay member in Alabama and its fauna is still very imperfectly known. Therefore, it seems preferable to retain the Chickasawhay in the Byram for the present rather than to give it formational rank.

The Chickasawhay marl member is exposed in cuts on the railroad and highway 1.3 miles north of Millry, Alabama, where it contains *Turritella mississippiensis* Conrad?, *Anadara* aff. *lesueuri* (Dall), *Ostrea vicksburgensis* Conrad, 3 species of *Pecten*, and *Anomia* sp. (station 13,381). In Clarke County, Alabama, it has been found at

[24] *Guidebook of the Eleventh Annual Field Trip of the Shreveport Geological Society into Southeast Mississippi* (1934), table facing p. 30. The "Limestone Creek beds" to which these species are credited are the lower half of the Chickasawhay marl; the "X-Y-Z beds" are the upper half.

[25] G. I. Adams, Charles Butts, L. W. Stephenson, and Wythe Cooke, "Geology of Alabama," *Alabama Geol. Survey Spec. Rep. 14* (1926). 312 pp., 97 pls., map.

Paynes Hammock on Tombigbee River, north of Salt Creek, at Gainestown Ferry, 1 mile north of Glendon, 1.7 miles southeast of Gainestown on the road to Lambards Landing, and at Choctaw Bluff. Near Perdue Hill, Monroe County, Alabama, it is underlain by dark gray clay that probably represents the Bucatunna member. It occurs on Murder Creek at Castleberry and a mile or more above Kirkland. The fossiliferous marl on Conecuh River at Weaver Chute and on Yellow River at Watkins and Henderson Bridge also appear to represent the Chickasawhay marl member. Most of these places are described in the "Geology of Alabama."

The correlation of the Chickasawhay marl with the Antigua limestone, suggested by Hanna and Gravell[26] because of the presence in both of *Lepidocyclina undosa* and *L. favosa*, is supported also by similarities in the mollusks. Several mollusks in the Chickasawhay marl resemble Antiguan species but are too poorly preserved to admit of positive identification. The writer considers the correlation of the Chickasawhay member with part of the Antigua limestone as very probable.

FLINT RIVER FORMATION

This suspected correlation of the Chickasawhay with the Antigua reopens the question as to the age of the chert beds in Georgia and southeastern Alabama, which also are regarded as of Antigua age because of their similar corals. In 1923, the writer showed that these beds belong to the Vicksburg group and he was of the opinion that they represented the Glendon limestone rather than the Byram marl, although the evidence on which that opinion was based was by no means conclusive.[27] That correlation was adopted in the "Geology of Alabama." For several reasons, the correlation of the chert beds with the Glendon now seems doubtful. One is the absence or great rarity of *Pecten poulsoni*, a species very common in most authentic occurrences of the Glendon. Another is the abundance of *Orthaulax*, a very widely distributed genus at certain horizons[28] but still unknown in true Glendon and typical Byram deposits. To be sure, *Orthaulax* has never been found in any other Vicksburg horizons in the United States, but the faunas of the Chickasawhay and Bucatunna members of the Byram are still largely unexplored. The fauna of the chert beds

[26] *Guidebook of the Eleventh Annual Field Trip of the Shreveport Geological Society into Southeast Mississippi* (1934), p. 29.

[27] C. W. Cooke, "The Correlation of the Vicksburg Group," *U. S. Geol. Survey Prof. Paper 133* (1923), pp. 5–8.

[28] C. W. Cooke, "*Orthaulax*, a Tertiary Guide Fossil," *U. S. Survey Prof. Paper 129* (1921), pp. 23–31.

appears to be more closely related to that of the Chickasawhay than to that of the Glendon.

In view of the uncertainty as to the exact stratigraphic position of the chert beds, it seems desirable to apply to them a formation name that can be shifted in correlation tables until its proper niche is found. Therefore, it is proposed to call them the Flint River formation.

The Flint River formation is placed opposite the Chickasawhay member of the Byram marl in the accompanying correlation table of the Vicksburg group, although the evidence that such is its correct position is not yet conclusive.

Fossils typical of the Flint River formation have been collected from lumps of chert or silicified limestone overlying the Ocala limestone on Flint River between Red Bluff, 7 miles above Bainbridge, Georgia, and Hales Landing, 7 miles below Bainbridge. The beds were described by Vaughan[29] as part of the Chattahoochee formation (a name no longer used). Dall[30] described the fauna in 1916.

CORRELATION OF VICKSBURG GROUP

<table>
<tr><th>Florida</th><th colspan="2">S. C.</th><th>Georgia</th><th colspan="2">Alabama</th><th colspan="2">Mississippi</th><th>Leeward Islands</th><th>Mexico</th></tr>
<tr><td rowspan="2">Byram marl</td><td colspan="2" rowspan="2">Absent?</td><td>Flint River formation</td><td colspan="2" rowspan="2">Bucatunna clay member</td><td>Chickasawhay marl member</td><td rowspan="2">Byram marl</td><td>Antigua formation</td><td>Meson formation</td></tr>
<tr><td></td><td></td><td>Alazan clay</td></tr>
<tr><td colspan="4">Absent?</td><td colspan="3">Glendon limestone</td><td></td><td></td></tr>
<tr><td>Marianna limestone</td><td colspan="2">Absent?</td><td colspan="2">Marianna limestone</td><td>Red Bluff clay</td><td>Mint Spring marl member
Forest Hill sand</td><td></td><td></td></tr>
</table>

Most of the so-called Glendon limestone of Florida[31] seems to be of the same age as the Flint River formation, with which it has been correlated. A possible exception is the limestone forming the lower 2 beds of the section on Suwannee River at Ellaville,[32] which may be somewhat older.

[29] T. W. Vaughan, in Otto Veatch and L. W. Stephenson's "Preliminary Report on the Geology of the Coastal Plain of Georgia," *Georgia Geol. Survey Bull. 26* (1911) pp. 329–32.

[30] W. H. Dall, "A Contribution to the Invertebrate Fauna of the Oligocene Beds of Flint River, Georgia," *U. S. Nat. Mus. Proc.*, Vol. 51 (1916), pp. 487–524.

[31] C. W. Cooke and Stuart Mossom, "Geology of Florida," *Florida Geol. Survey Twentieth Ann. Rept.* (1929), pp. 67–73.

[32] *Ibid.*, p. 72.

TAMPA LIMESTONE AND CATAHOULA SANDSTONE

The *Guidebook*[33] includes a report by Hanna and Gravell on cores and cuttings from a well drilled somewhere in south Mississippi[34] in which the Chickasawhay marl member of the Byram, recognized by the presence of *Lepidocyclina*, is overlain by 200 feet of sand and clay, which underlies about 150 feet of chalk and sandy limestone containing *Sorites*. In Florida *Sorites* occurs in the Chipola formation, and is common in the Tampa limestone, but it is unknown in older formations. It seems probable, therefore, that the chalk and sandy limestone represent the Tampa and perhaps also the Chipola and that the underlying sand and clay represent the Catahoula sandstone, which overlies the Chickasawhay marl at the outcrop. If this correlation is correct, the Catahoula sandstone is older than the Tampa limestone—not contemporaneous with it as has been supposed without proof.

If the Catahoula, which is younger than the Chickasawhay, is older than the Tampa, it is probably not Miocene but Oligocene; for the Tampa has been correlated with the European Aquitanian, which is regarded by some geologists as the lowermost stage of the Miocene and by others as Oligocene. The Catahoula may be equivalent to the European Chattian, which intervenes between the Aquitanian and the Rupelian, with which Flint River has been correlated.

The writers of the *Guidebook* proposed to group the Bucatunna clay, the Chickasawhay marl, and the Catahoula sandstone together in what they called the "Catahoula group." The limestone, marl, dark clay, and thin-bedded or laminated sand of the Chickasawhay and Bucatunna are very similar to materials in other parts of the Vicksburg group but are in striking contrast to the light-colored sand, sandstone, and massive clay that compose the greater part of the Catahoula sandstone. The possible unconformity at the base of the Bucatunna may have less significance than the probable unconformity at the top of the Chickasawhay noted south of Waynesboro, Mississippi, and at Choctaw Bluff on Alabama River. For these reasons it seems undesirable to put the Catahoula sandstone in the same group as the Chickasawhay marl and Bucatunna clay. Moreover, the fauna of the Catahoula is unknown. The writer has seen a few obscure marine mollusks in a railroad cut near D'Lo, Simpson County, Mississippi, but they were too poor for identification.

[33] *Op. cit.*, pp. 19–22.

[34] The identity of this well was not revealed.

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GLACIAL EXPRESSION OF STRUCTURAL FEATURES IN MICHIGAN: PRELIMINARY STUDY[1]

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ABSTRACT

Each field that has been drilled in Michigan adds a small bit of evidence in one form or another to the writers' belief that there are various directional relations between glacial features and structure. These relations are not always the same, but several of them have existed in more than one field and it appears that structure controlled glaciation to a greater or lesser degree in all of them. Therefore, one should look for morainic ridges oriented with structure, thin drift, artesian areas in the drift, sharp changes in stream directions that bend basinward, intensified meanders, distribution of pit lakes, alignment of elongate lakes that extend in wide sweeps and sharp basinward loops, and the general spacing of moraines and other prominent divides. The exact way that these surface features of glaciation fit into the structural picture will remain a matter of interpretation as long as wells are scattered and far between. Observations thus far seem to reveal somewhat consistent relations, and, though indefinite in places, the glacial expression of structure continues a fertile field for conjecture.

INTRODUCTION

The common conception of many geologists working in glaciated regions, such as Michigan, is that there is no very definite relation between features of glaciation and the structure of the bed rock underneath them. It is generally thought that the effect of glaciation is to plane down those topographic remnants that are clues to the presence of anticlines. The prevalent belief is that, if some physiographic expression of structure remained after the continental ice covered the area, it was largely obliterated by the repeated advances and retreats of the ice occurring at different times and in varying directions. The premises on which these conclusions are based must be weighed carefully in any attempt to set up specific criteria that certain types and arrangements of glacial deposits are caused by structural features to be found in the rocks below.

The writers do not believe that it is possible arbitrarily to determine, from any particular set of conditions in the glacial surface deposits, the structural conditions in the underlying rocks. Their con-

[1] Read before the Michigan Academy of Science, March, 1935. Manuscript received, March 22, 1935. Published with the permission of the State geologist.

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viction is, however, that, after a study of meager subsurface structural data in a sparsely drilled drift-covered region, the surrounding glacial geology may so logically fit into the hypothetical picture as to add strong clues supporting one interpretation of structure over others. The relations borne out in one area will not always fit into another, and each problem of correlating glaciology and structural geology will have to be attacked with as complete understanding as possible of the various factors involved.

This paper presents a digest of some of these factors and applies them to several areas of known structure in the Southern Peninsula. A few of them have been mentioned previously and are catalogued here only for the sake of completeness. The new ones mentioned may raise questions and further develop this type of structural study. The glacial deposits on or near known anticlines have presented several interesting relations, and the regular distribution of other features of glaciation seems to correspond rather closely with a pattern of structural "trends." The effects of the continental ice have not completely obliterated the surface expression of the structural pattern, and it is believed that, as more is learned about lines of folding across the state, many new comparisons of glaciation and structure will be found.

In the search for glacial expression of structural features, the limitations of the criteria must continually be kept in mind. If this is done, the comparisons thus far revealed can be expanded with others and by proper interpretation be put to useful economic purpose in the search for new anticlines ahead of known oil and gas pools.

TOPOGRAPHIC EXPRESSION OF STRUCTURE IN UNGLACIATED AREAS[4]

Any interpretation of structural conditions beneath a mantle of drift from surface observations requires knowledge of the topographic expression of structure in an unglaciated area. This is discussed briefly here with a résumé of the major factors determining it.

The first major factor is the type of structure. Faulted structures tend to cause definite alignments of outcrops without regard to regional and local dips. Folded structures cause irregular escarpments where they plunge into regional basins. These escarpments extend basinward over the fold, up the regional dip in the synclinal areas, and the width of outcrop generally indicates the amount of dip. Thus, low, gentle folds cause broad areas of outcrop with numerous outliers.

[4] F. H. Lahee, *Field Geology*, 2d edition (McGraw-Hill Book Company, Inc., New York, 1923), pp. 185–90.

Sharp folds cause narrower belts of outcrops, extending around them, and sharp, hogback ridges more or less parallel with the strike of the fold. Exposures of thick formations also cause a broad areal expanse of outcrop similar to low folds. However, with the exception of shale formations, these thicker formations have a tendency to weather down and form escarpments on the outcrop of the harder members. Folds paralleling the regional strike or flanking a basin are not easily detected, though the basinward escarpments may be sharp and well defined. The reverse dips on folds of this type may show little, if any, outcropping of rock, and a few straggling ill-defined outliers will tend to confuse, rather than aid, correct structural interpretation. Generally, a low ridge marks the remnant of a weathered bed, and to decide whether this is the same bed or an underlying one is likely to be confusing.

The second major factor is that of the nature or type of rocks. Because of their low topography, the relief of areas underlain by large shale bodies or other fast weathering rocks has very little structural significance. In areas of hard resistant rocks, such as sandstones and some limestones and dolomites, hills or ridges are likely to be synonymous with structure. Areas of hard and soft rocks generally have a rugged relief with outcrops flanking the anticlines. Similarly, limestone areas are ordinarily found with the valleys on top of the fold and the ridges of outcrops on the flanks of the fold or in the synclines.

The third major factor is the degree of folding. In gently folded areas or areas of low relief, hills are more likely to reflect structure, and dip slopes are common. In areas of pronounced relief, escarpments are practically synonymous with off-structure dip or synclinal areas. "Escarpments" as here used should not be confused with "outcrops."

A fourth major factor is the type of climate that prevailed during the weathering of the rocks to their present topography. Humidity creates one type of relief and aridity another. Climate that changes through a wide range can cause many variations between the two types of relief.

GROWTH OF GLACIATION

A popular conception of the glacial period in the lay mind is one of an ice sheet that appeared suddenly, advanced over a large area carrying all obstruction before it like a gigantic plow, retreated, and advanced, repeating the process until all previous semblance of topography was entirely obliterated or masked by an increasing blanket of drift. This belief needs some modification.

The encroaching glacial cycle was not sudden. It probably was

accompanied by a gradual change in seasons, consisting of a lengthening of the winter months and a shortening of the summer months. The growth of the ice and snow blanket occurred gradually and simultaneously almost everywhere. Its thickness, of course, was greatest in northeastern and northwestern Canada. Perhaps thousands of years elapsed before any movement of the ice mass occurred. The movement outward toward the edges was similar to that of a viscous mass, being mostly on the surface in an upward and outward rolling movement. It is hard to conceive that after formation this ice mass had much planation effect on the bed rock, which was already covered by an ice sheet that acted as a gliding surface for this movement. That local plucking, dragging, and gouging of the bed-rock surface occurred to some extent is admitted, but the irregular bed-rock relief shown by wells indicates that planation was not widespread. This gouging effect probably tended to intensify the existing relief rather than destroy it. It is well known that this is what a mountain glacier does in going down a valley.

With the retreat of one movement and the advance of the next, the same cycle of ice burial was repeated so that major patterns once established evidently remained essentially the same.

The direction of major glacial ice movements is common knowledge, and that these advances were over areas of low relief indicates that ice movement either was greatly aided or retarded by existing topography. It is not difficult to believe that minor features may have had a similar effect also in acting as "rudders" on these movements.

Any observer can see that much of the material in the drift did not come from the Paleozoic formations of the Michigan basin. A study of the relative distances involved in the ice movement reveals that the width of the Michigan basin is perhaps less than one-fourth of the distance from the major source of the ice. It is only natural to assume, therefore, that the bulk of the drift was carried here and deposited at the melting edge of the advancing ice sheet. That basal ice movement occurred over great distances is hard to prove or disprove. However, the areas of thin drift in northeastern Lower Michigan suggest that the ice that moved over it came from the old Lake Huron valley and was comparatively free of rock débris. It apparently advanced a relatively short distance and left little, if any, drift on melting.

The advance of the ice front is anomalous in that it was always retreating because of the constant melting of its southernmost edge; it is only natural to suppose, therefore, that the constantly accumulating mass of drift at the ice edge was being deposited irregularly. The

obstructions of existing escarpments and topographically high areas acted similarly upon the ice flow as any obstruction in a silt-laden river, causing eddies and backwash with a resultant dropping of part of the load. The types of glacial deposits are so well known that they are not re-defined here. However, a classification into major groups may impress one with their relative significance in this problem. Roughly, they can be grouped as marginal, submarginal, basal, and englacial. Marginal deposits, such as outwash plains, indirectly suggest structure because they represent areas that were swept and covered by outwash from a more or less stagnant ice front. The high outwash plains of north-central Michigan mask the largest high bed-rock plateau in the Lower Peninsula, and it is only natural to assume that this high plateau caused the ice stagnation and the resultant outwash. Submarginal deposits, such as moraines, are apt to reflect significantly controlling features below them. Basal deposits, as till plains, possibly may reflect bed-rock control. Englacial deposits, such as eskers, are apt to be superimposed on various types of glaciated land surface, and a few geologists believe them related in some way or other to areas of thin drift.

All glacial deposits assume relative significance when they are classified as to the manner in which they were laid down. Deposits laid down by an advancing ice sheet are more important than those laid down by a retreating one. The constricting patterns of moraines marking the retreat of the Saginaw ice lobe show little, if any, reflection of structure beneath them. Morainic belts laid down by stagnant ice sheets may have considerable importance. The large moraines encircling the area of outwash in north-central Michigan are strongly suggestive of structural control. Deposits formed in or by impounded glacial lakes, such as large deltas and the various beaches, appear to have a certain amount of structural significance.

As the ice retreated and buried ice masses completely melted, lake and drainage patterns were established. Prominent escarpments and high areas of Marshall sandstone caused many buried ice masses and an exceptional number of pit lakes. In certain areas, these lake patterns molded themselves around known anticlinal structures in a manner that is too striking to be accidental. Similarly, drainage patterns show rather uncommon characteristics where they cross lines of structural uplift.

TYPES OF GLACIAL EXPRESSION

The final retreat of the glacial ice left three main types of expression which have since been somewhat changed by weathering

processes and post-glacial uplift. These were the topographical features, the impressed drainage features, and the inland lakes of glacial origin or the features of impounded drainage. Each of these types of glacial expression has preserved a certain pattern of the rocks beneath them despite the later changes undergone since their inception.

TOPOGRAPHIC EXPRESSION

It has been shown that there is considerable relief on the surface of the bed rock beneath the drift. The pattern of the valleys and divides on the rock surface beneath the glacial cover in some places strongly resembles the pattern of known folding across the same region. Many of the striking parallelisms of bed-rock topography indicate that folding in the rocks influenced and largely governed them. The problem of just how this occurred in any one particular region involves careful examination of the character of the rocks themselves and requires as much knowledge as possible of the local history of glaciation.

The glacial-bed-rock surface is essentially an unconformity with a known total relief in Michigan of more than 900 feet. This contact is like most other surfaces of unconformity in that it generally has a detrital zone and is not always sharp. Observation of planed rock surfaces on some glaciated exposures and in some quarries where the drift has been stripped off has brought about the common conception that the general effect of glaciation was to level off and thus destroy topographic features. That this was not true in some of the larger physiographic features has been previously explained through the analogy of deepening of valleys due to mountain glaciation. In many places the glacial ice plowed and scoured and deepened the valleys before it removed the less stable remnants and planed off the escarpments.

Any interpretation of structure from the glacial features of the state requires the most definite knowledge possible of regional formation boundaries. Each line of folding extending basinward could give rise to every possible mode of topographic expression and must be interpreted accordingly. It can readily be seen that glacial expression of areas underlain by Coldwater shale should be vastly different from that of areas where the bed rock consists of Marshall sandstone. All structures flanked by Marshall outcrops and whose crests are of soft Coldwater shale show definite valleys on the rock surface and some on the drift surface.

The Marshall sandstone escarpments on the side of the strongest dip along two Michigan lines of anticlinal folding are well preserved

underneath the glacial drift. These features at Howell and West Branch are well known from adequate drilling, and their details have been previously shown either on maps or in discussions. The Broomfield structure in western Isabella County is underlain by Permo-Carboniferous (?) sediments, and it is notable that the southwest or fast dip side has an abnormal thickness of "red-beds" beneath the drift. Similar conditions should be found where the crests of structures are occupied by shales and the flanks are the more resistant rocks.

This leads to the controversial subject of the orientation of moraines with structures. The writers are convinced, however, that possibilities along this line should not be completely forgotten and an open-minded attitude should be maintained. If bed-rock ridges are preserved along structural trends, it is logical to look for the orientation of some of the terminal moraines with such ridges. In the Broomfield gas area of Isabella County, the strong dip of the structure where production cuts off to the west is overlain by a line of high morainic hills. The strong west dip off the Howell structure, Livingston County, is marked locally by the pronounced morainic ridge west of the city where the State Tuberculosis Sanitorium is located.

The definite alignment of outcrop and drift patterns in the northern half of the Southern Peninsula suggests the presence of faulted areas. The length of these lines of moraines seems more suggestive of fault control than of normal outcrop patterns.

In many parts of the Southern Peninsula, divides and principal watersheds are oriented or coincident with known lines of warping. One has only to take a map of the various river systems of the state and compare it with a regional subsurface structural contour map to see the similarities. The main watershed through central Michigan changes trend markedly from northwest and southeast in the southern part of the peninsula to nearly north and south in the northern part of the peninsula. This is more or less coincident with the change in direction of main lines of folding which occurs north of the center of the Michigan basin. In some places there is locally no evident relation of this type, but divides extending ahead of known trends of folding must be considered in making future deductions on the prolongation of folds suggested by new wildcat drilling. An excellent example of the coincidence of a structural anticlinal axis with a prominent divide is in the vicinity of Ashley and Bannister, Gratiot County. The location of the spillway of the Grand River outlet from glacial Lake Sagina v in the vicinity of Maple Rapids, Clinton County, is evidently related to an indefinitely established anticlinal axis.

Some important divides are formed by the more resistant rocks

beneath the drift, such as the Marshall sandstone. Here one must look for the breaks in the divide, as at Howell and West Branch, where structures are known, and at other places where they are thought to be present. If a morainic system forming a divide is known to follow a belt of resistant rocks, as the Port Huron moraine does in the northern part of the Southern Peninsula, a change in the direction of this system is indicative of a change in direction of the strike of the underlying rocks. Changes in strike generally indicate structure, and so it is extremely probable that important lines of folding known to cross central Michigan extend northward in the general region of this important indentation in the Port Huron morainic system.

Following out the same line of thought, interlobate moraines generally are indicative of diyides and in many places are higher than the surrounding terminal moraines. Many boulder belts are associated with interlobate moraines, and the trend and localization of these is another form of topographic expression which may be related to structure.

In the southwestern part of the state, there are angular and rectangular patterns of major terminal moraines. Where these moraines change sharply in direction, the points of the angles are generally basinward, and this brings up the question of whether or not they may, in some places, swing around underlying bed-rock escarpments. An angularity similar to this is exhibited in northeastern Michigan. These patterns, which may be later found aligned with known axes of folding, are suggested as possible correlatives in some form or other with structures yet to be discovered. The alignment of moraines can be helpful in forming correct opinions of structural conditions, even though the relation between the two may vary widely in different places.

DRAINAGE EXPRESSION

Many years ago, Alexander Winchell[5] pointed out the diagonal drainage pattern in the major river systems of Michigan, and now that more is known about folding across the state this pattern has added meaning. Drainage in this state, as in all glaciated regions, is chiefly haphazard. It has been observed, however, that the courses of some major streams seem to outline remarkably well the positions of structural axes. This relationship is manifested in several different ways. Muskegon River makes sharp turns which are spaced somewhat regularly along its course and which generally point into the center

[5] Alexander Winchell, "The Diagonal System in the Physical Features of Michigan," *Amer. Jour. Sci.*, 3d Ser., Vol. VI (July, 1873), pp. 36–40.

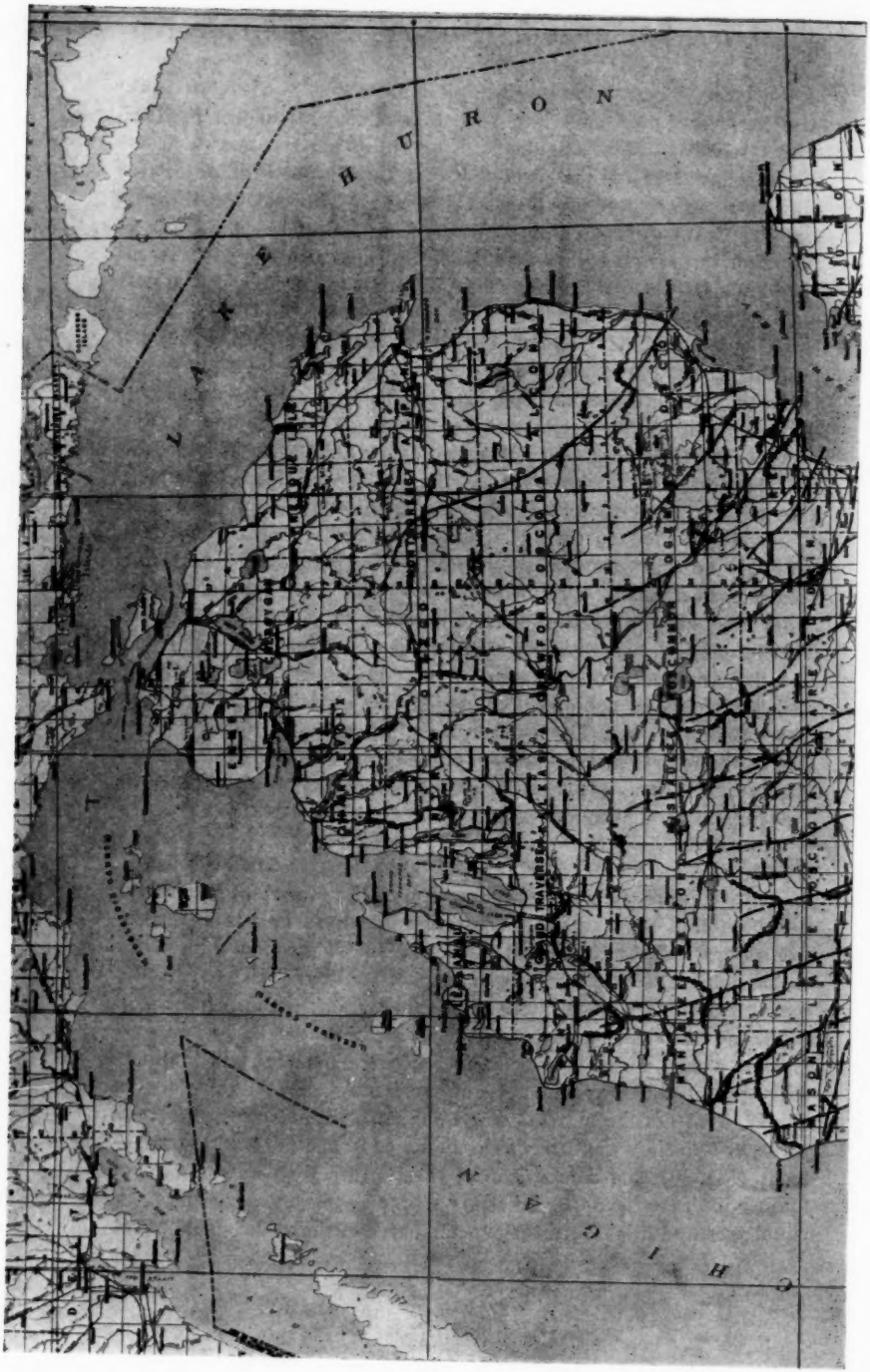
of the basin. These turns suggest plunging noses, and the straight stretches may be on one side or another of an anticlinal axis. The comparatively straight alignment of several other streams, such as the Tittabawassee and the lower courses of the Huron, Rifle, and Pere Marquette, may have structural significance. The wide northward swing of Grand River in the vicinity of Grand Rapids has attracted attention, but efforts to interpret the structural reason for this feature have thus far seemed fruitless. Several similar spacings and alignments are suggested by dotted lines on Figure 1, and it will be interesting to watch developments revealing more exactly how they fit into the general pattern of folding across the state.

In the northern part of the Lower Peninsula, where streams cross lines of folding, they seem to be deflected southward, and in the southern part they are deflected more toward the north. This deflection is generally basinward so as to indicate the possibility of plunging axes with scarps curving convexly toward the center of the basin.

Several of the structures that have been drilled and more or less definitely outlined are crossed by fair-sized streams. In the Mount Pleasant, Porter, and West Branch fields, the streams seem to meander more closely across the structures than on either side of them. This intensified meandering may be mere coincidence, but the fact that the same condition is present in many places where streams cross anticlinal folds in non-glaciated regions makes it appear that the presence of structure has a controlling influence. If this is true, it follows that where streams cross supposed lines of folding rather than bend around them, meander patterns should be as closely studied in a glaciated region as in any other.

LAKE EXPRESSION

In explaining the writers' conception of the growth of glaciation, it was pointed out that prominent escarpments seemed to affect the size, shape, and localization of pit lakes. One of the first things that strikes one's eye on examining a map of southern Michigan is the concentration of lakes in areas underlain by, or up the regional dip from, the Marshall outcrop. This concentration of lakes, when outlined on a map, forms indented and concentric patterns which apparently reflect the Marshall not only regionally, but in some places locally. This outline of areas where inland lakes are most numerous seems also to show that they are segregated in angular zonal arrangement (Fig. 2). The comparison of these zones with known axes of folding indicates that the lakes are scarce or absent along the anticlinal axes and thickest in the synclinal areas. It is a curious fact that


LAKE HURON
MICHIGAN

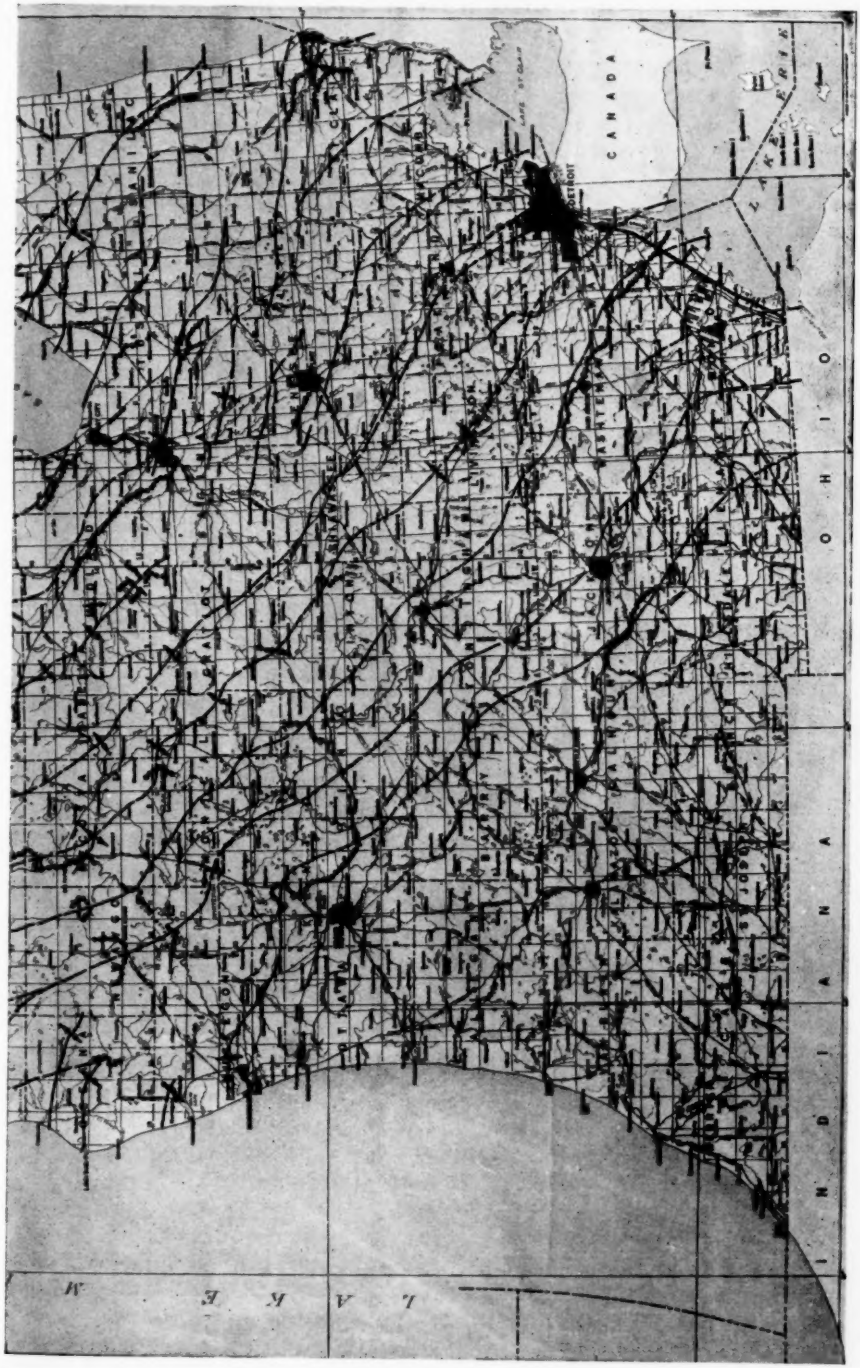


FIG. 1.—Map of southern peninsula of Michigan showing: known anticlinal folds (arrows); postulated anticlinal axes (broken northwest-southeast lines); and exceptional stream patterns (dotted lines). Base map, Michigan Department of Conservation from U. S. Geological Survey. Scale: approx. 3/16 inch = 6 miles.

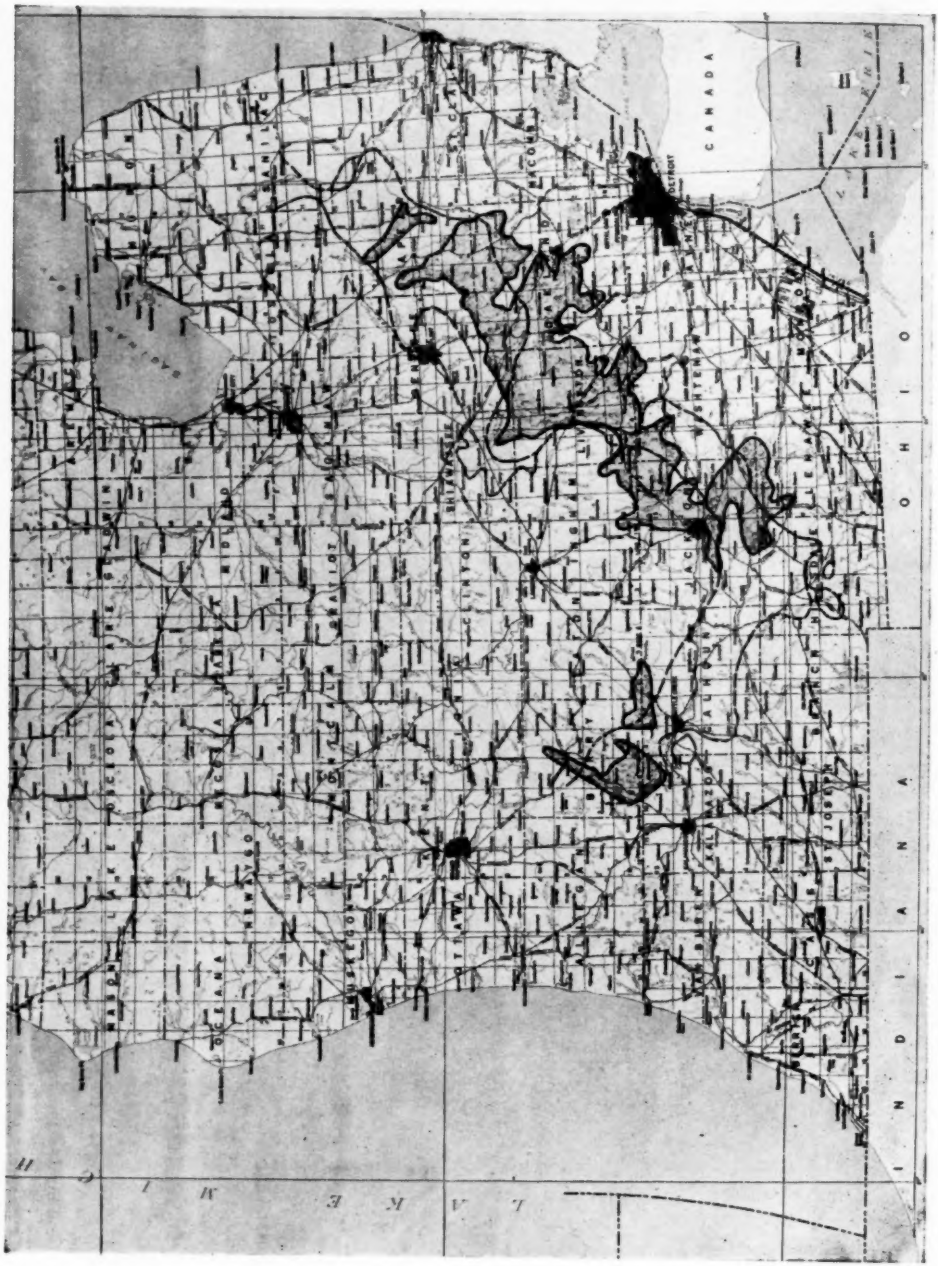


FIG. 2.—Map of south part of southern peninsula of Michigan showing inland lake areas (shaded) and boundaries of Marshall outcrops (broken lines). Base map, Michigan Department of Conservation from U. S. Geological Survey. Scale : approx. 7/16 inch = 15 miles.

none of the oil fields discovered to date in Michigan extends across an inland lake of any size. This does not mean, of course, that such a thing will not occur, as it is readily conceivable that a glacial pit lake might occupy a depression left by a structural valley, but so far this has not occurred. There are indications that in some places swamp areas do this, but these possibilities can not refute the facts of what has occurred. The segregation of lakes in several synclinal areas seems well established.

The orientation of the lakes forming harbors along the Lake Michigan shore seems exceptionally regular, and the way the Muskegon field bends around the north side and the east end of Muskegon Lake may be significant. The lakes at Saugatuck, Holland, Grand Haven, Muskegon, and Whitehall have similar orientations and are somewhat uniformly spaced, but their orientations change from northeastward to southeastward with change in the strike of the rocks (Fig. 3).

The somewhat elongate inland lakes of several counties in central Michigan, where active drilling is in progress, extend in broad sweeps along more or less definite lines that seem to correspond with outcropping escarpments beneath the drift and suggest the regional direction of structural trends. This seems particularly true in Montcalm County and possibly in Clare County. The shapes of some lakes suggest structural noses and sharp changes in the strike of the underlying rocks, but the complete proof of this relation is still to be worked out by further drilling. The patterns of lakes in the southwestern part of the state are indefinite, but may reflect old pre-glacial drainage lines. If buried escarpments determine the localization of pit lakes in some areas under certain conditions, it will be necessary from a practical standpoint in directing exploration to find out whether they are on the inside or outside of escarpments of off-structure dip. To do this, a close study of glaciation in the region and several wells for control will be required.

In studying the various lines of structure across southeastern Michigan and the Saginaw Bay region, it has been observed that the beach lines of former stages of the Great Lakes during the glacial period are indented at comparatively regular intervals (Fig. 4). These indentations are spaced about the same distance apart as the structures that are thought to trend across the area where the beaches exist. Some of these indentations are occupied by deltaic deposits, showing that they were due to the mouths of streams flowing into the Great Lakes of glacial time when the waters stood at higher levels than at present. The axis of the Howell structure seems to cross the

FIG. 2.—Map of south part of southern peninsula of Michigan showing inland lake areas (shaded) and boundaries of Marshall outcrops (broken lines). Base map, Michigan Department of Conservation from U. S. Geological Survey. Scale: approx. 7/16 inch = 15 miles.

FIG. 3.—Map of Michigan showing: areal lake pattern (shaded); angular river pattern (crooked lines within circles); area of post-glacial change in drainage divide (horizontal line within circle); alignment of Lake Michigan embayments (diagonal lines on east shore of Lake Michigan); and suggestive regional alignments (northwest-southeast broken lines across state). Same base map as used in Figures 1 and 2. Scale: approx. 1/8 inch = 6 miles.

Maumee and Whittlesey beaches near their indentations between Northville and Plymouth, Wayne County. This would suggest that other structural anticlinal axes cross these beaches in the vicinity of the other indentations. The place that they crossed probably depended on whether the stream flowed on the east or west side of the off-dip structural escarpments. This will not be known until more drilling has been carried on.

The indentations of the beach directions on the north and west sides of glacial Lake Saginaw seem to define the east-west trend of the Mount Pleasant-East Extension pool, the new Beaverton structure, Gladwin County, and the northwest trend of the arch in the vicinity of Kawkawlin, Bay County. Other great delta areas farther north of Saginaw Bay may have similar significance, but the structural control is meager and there is no suggestion of possible relationships from wells that indicate folding.

EXAMPLES OF GLACIAL EXPRESSION

In discussing the various types of glacial expression of structure, several examples have been cited. Several maps have been prepared to show these and also to suggest other projected interpretations. These maps do not represent final deductions, but simply outline relations which seem to merit some consideration.

On Figure 1 the known and some of the postulated anticlinal axes are indicated by curved and dashed lines. The dotted lines emphasize the stream alignments that seem to correspond with the structural pattern and the wide stream bends that may have been governed by the drift-buried escarpments which outline plunging noses.

Figure 2 shows the area of important inland lake regions in southern Michigan by shading and heavy black outlines. The boundaries of the Marshall outcrop are marked on the map in heavy dashed lines so as to show how these lake regions are coextensive with the general area underlain by the Marshall.

On Figure 3 the lake regions are outlined throughout the Southern Peninsula in an effort to show that they are prevalent in synclinal regions. Various alignments with areas of known structure are attempted.

Figure 4 is Leverett's "Map of the Surface Formations of the Southern Peninsula of Michigan" (1924), on which have been marked the moraines that seem to be parallel with known lines of folding, the angular and significantly curved morainic features, and the regular indentations along the glacial lake beach lines.

DEPARTMENT OF CONSERVATION OF MICHIGAN
JOHN BAIRD, Director
GEOLOGICAL SURVEY DIVISION
E. A. SMITH, State Geologist
IN COOPERATION WITH THE UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director
MAP OF THE
SURFACE FORMATIONS
OF THE
SOUTHERN PENINSULA
OF
MICHIGAN
BY FRANK LEVERETT, Geologist, U. S. Geological Survey
IN COOPERATION WITH FRANK B. TAYLOR AND ESSEMS OF THE
GEOLOGICAL SURVEY DIVISION
DEPARTMENT OF CONSERVATION OF MICHIGAN
1924
EDITION PUBLISHED IN COOPERATION WITH STATE DEPARTMENT OF AGRICULTURE
TO CHARLEVOIX COUNTY
TO ANTRIM COUNTY
MACKINAC STRAIT
LAKE HURON
LAKE MICHIGAN
SAGINAW BAY

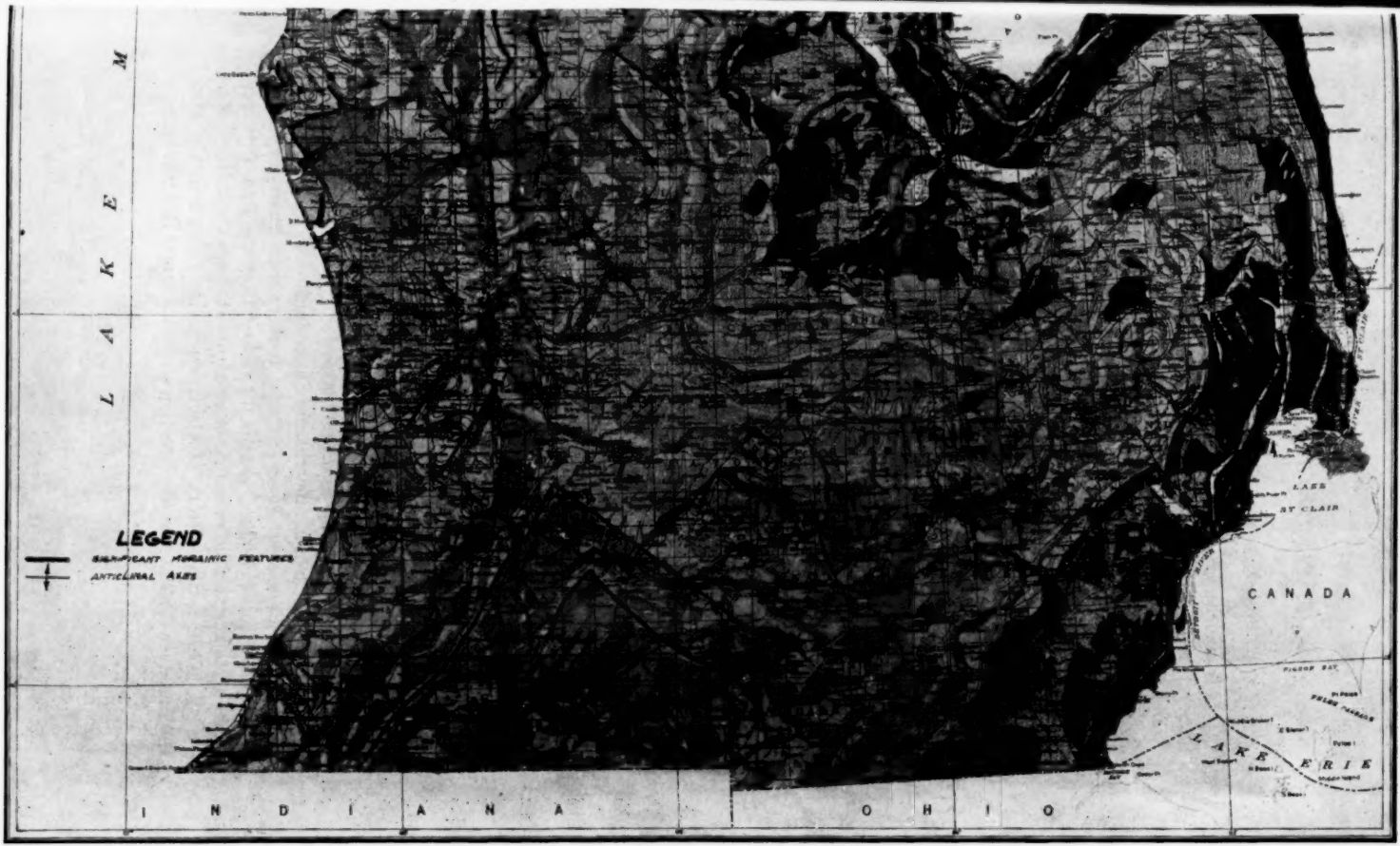


FIG. 4.—Map of southern peninsula of Michigan showing significant morainic features (heavy black lines) and anticlinal axes (arrows) on areal geology base map.

EXPRESSION OF POST-GLACIAL UPLIFT

It is evident from what is known of folding in the state that the general trend of the hinge lines of post-glacial uplift follow the general trend of lines of warping across the eastern side of the basin. These hinge lines are in several places closely coincident with folds, such as those crossing Saginaw Bay between Huron and Arenac counties, but in other places they correspond only in direction. The spacing of zero isobases for individual beach systems of the various lake stages is wider than the spacing of lines of folding across central Michigan. The northward uplift of beaches does not become large for most stages until north of Saginaw Bay. This may be related to more intense folding in that direction as indicated by intense folding of the Ogemaw district in comparison with that of the central Michigan area.

POSSIBLE CRITERIA OF GLACIAL EXPRESSION OF STRUCTURE

If it be accepted from the preceding examples that, under certain conditions, the topographic, drainage, and lake features caused or modified by glaciation may reflect the structure of the rocks underneath, it follows that the question of future observations along this line is paramount. What are the criteria that can be applied in making these observations and what are the limitations of the method? At best, the method is only a "cut-and-try" proposition. In introducing this subject, the writers have tried to emphasize that many notions of structure indicated by glacial features might be incorrect.

The writers endeavor to outline some of the factors that must be considered in carrying on such a study.

1. Are there enough scattered wells to limit the interpretation of structural conditions to only a few possibilities?

2. Do glacial features tend to support or refute any of these possibilities?

3. Can the directional elements or trends of a known pattern of structure in adjoining regions be identified in any of the glacial features of the area under study?

4. What are the underlying rocks? Are they subject to solution? Do they have prominent escarpments?

5. Are the scarps of off-structure dip on both sides of the structure or simply on one side? If on one side, is there more than one scarp?

6. If the drift is thin, what is the cause? Does the thin drift contribute to the surface reflection of structure through the drift?

7. What is the history of glaciation as interpreted in the area under study? What was the direction of the ice front? Did this change

during glaciation of the local region? What was the direction of the ice movement? Did it change or was it somewhat uniform?

8. Do the glacial features have regular distribution and arrangement corresponding to the distribution and arrangement of near-by known structural features?

9. What are different relations of glacial features to structural features on those domes already adequately outlined by drilling?

10. Are the glacial features of sufficient size and scope to be governed by the structure of the rocks beneath?

11. Does the orientation of glacial features seem to correspond to the boundaries between hard and soft rocks as understood?

12. Will the distribution of hard and soft rocks and the type of weathering prior to glaciation make a high bed-rock surface anticlinal or synclinal?

13. Are artesian conditions in the drift related in any way to buried bed-rock escarpments?

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OLIGOCENE TUMEY FORMATION OF CALIFORNIA[1]

E. R. ATWILL[2]
Los Angeles, California

ABSTRACT

In the Cantua-Panoche Creeks district, which is about 25 miles north of Coalinga, Fresno County, the writer discovered a diagnostic assemblage of Oligocene fossils in a sandstone previously assigned to the Vaqueros of Lower Miocene age.

Conformably overlying this sandstone and associated with it to comprise the Tumey formation is a somewhat diatomaceous shale which is locally rich in *Foraminifera*. The writer studied these *Foraminifera*, compared them with those collected in shales of known Eocene and Oligocene age, and herein points out what he believes to be a present erroneous identification of a common species in the Oligocene.

Possible regional correlations of the Tumey formation are made, and reasons are given for segregating under a new name this sandstone and shale sequence which is a cartographic unit for at least 7 miles in the district examined, and which reaches a thickness of about 1,600 feet in maximum exposure.

INTRODUCTION

An opportunity to study the stratigraphy and paleontology of the various sedimentary rocks occurring between the Moreno (upper Chico Cretaceous) and the Temblor (Miocene) formations in the Cantua-Panoche Creeks district north of Coalinga, Fresno County, California, disclosed an Oligocene faunule in a sandstone previously assigned at different times to the "Vaqueros" formation and to the Kreyenhagen formation.

The conclusions expressed herein are that this sandstone, together with the shale which conformably overlies it, an aggregate maximum exposure of about 1,600 feet of strata, should be grouped into a single formation, given a new name, and be placed in the Oligocene series, as this term is now used in Pacific Coast stratigraphy.[3]

LOCATION

The area in which the strata under discussion occur lies along the western border of the San Joaquin Valley in the Ciervo Hills, western

[1] Manuscript received, May 14, 1935.

[2] Geologist, Union Oil Company of California. The writer is indebted to Hubert G. Schenck and R. M. Kleinpell for assistance in the preparation of this paper, and to Mary G. Rathbun, Charles W. Merriam, and Leo G. Hertlein for their determinations of the fossils listed.

[3] The term "Oligocene" is used here, as elsewhere in this paper, in the sense generally employed in the western United States. Hubert G. Schenck, following a study of the Oligocene of western Europe, is planning to discuss the validity of this term at a future date.

FIG. 1.—Outline map of California, showing location of area mapped in Fresno County.

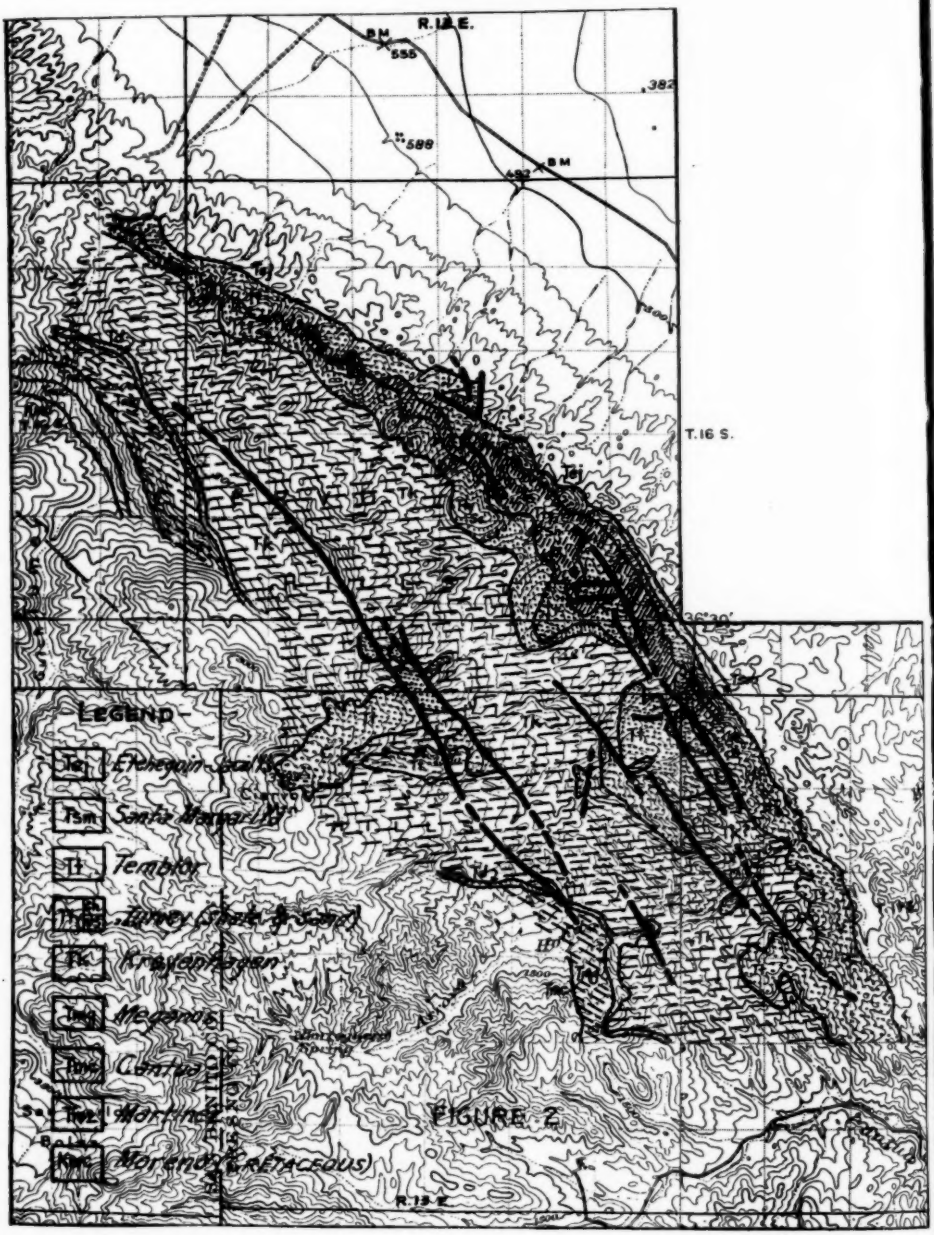

FIGURE 2.

FIG. 2.—Map showing surface geology of area between Tumey Gulch on northwest and Cantua Creek on southeast. Topographic base of United States Geological Survey. Scale, 0.5 inch = 1 mile. Topographic contour interval, 100 feet.

Fresno County, California. More in particular, it comprises a strip of territory averaging 5 miles in width and 17 miles in length between Cantua Creek on the southeast and Tumey Gulch on the northwest (Fig. 1). The valley entrants of these intermittent streams lie respectively in Sec. 36, T. 17 S., R. 14 E., and Sec. 30, T. 15 S., R. 13 E., Mount Diablo Base and Meridian. Coalinga lies about 20 miles by road southeast of the southerly limits of the area, and Fresno about 50 miles east of the northerly limits.

STRATIGRAPHY

The name Tumey formation is proposed for the sandstone mapped by Anderson and Pack[4] as faulted "Vaqueros" (just north of Arroyo Ciervo) and to the immediately overlying shales. This sandstone and shale sequence comprises a cartographic unit for a distance of at least 7 miles between Arroyo Ciervo and Tumey Gulch (Fig. 2). Southeast of Arroyo Ciervo, the sandstone appears to grade into shale. A short distance northwest of Tumey Gulch, it is overlapped by a sandstone determined to be of Temblor age on the basis of the following incomplete faunal list.[5]

"Mytilus" mathewsonii Gabb var. *expansus* Arnold
Ostrea titan Conrad (small variety)
Pectan andersoni Arnold
Pecten crassicardo Conrad
Scutella merriami (F. M. Anderson)
Turritella ocoyana Conrad

There is an unconformity at the base of the Temblor sandstone. This was recognized by Anderson and Pack,[6] who, referring to the Temblor as "Vaqueros," wrote:

> South of Panoche Creek, it (meaning their Kreyenhagen[7] shale) is overlain by the Vaqueros formation . . ., with which it shows distinct angular unconformity.

This unconformity is clearly figured by them on Plate IX-B of the same report. Its significance is apparent.

The shales immediately below this unconformable contact are more than 800 feet in maximum thickness at the vicinity just north of Arroyo Ciervo; but, being overlapped by the Temblor sandstone,

[4] Robert Anderson and R. W. Pack, "Geology and Oil Resources of West Border of San Joaquin Valley, North of Coalinga, California," *U. S. Geol. Survey Bull. 603* (1915), Pl. I, T. 16 S., R. 13 E.

[5] Collecting locality: near center of SE. ¼ of Sec. 28, T. 17 S., R. 14 E.

[6] *Op. cit.*, p. 76.

[7] The writer evades the complicated problem of the correlation of the shale here called "Kreyenhagen" with the Kreyenhagen shale at its type locality south of Coalinga.

they gradually wedge out toward the northwest. They consist chiefly of chocolate-brown-to-tan, diatomaceous shales (which weather whitish-to-purplish), with here and there ashy and brown sandstone beds, and limestone lenses. Their lithologic appearance is similar to that of the upper part of the "Kreyenhagen" shale.

The upper 20 feet of these shales, directly below the Temblor sandstone in the area near Arroyo Ciervo, contains a zone characterized by a pelecypod commonly called "*Leda*" *washingtonensis* Weaver. Some recent workers in the area report an unconformity about 185 feet below this contact, separating the so-called "*Leda* shale" from the main mass of the Tumey shale below. However, because of its identical lithologic characteristics and faunal content with the Tumey shale, and because it is in no sense a cartographic unit, the writer here classifies the "*Leda* shale" as the upper zone of the Tumey shale. Within a quarter of a mile both northwest and southeast from Arroyo Ciervo, the "*Leda*" zone is overlapped by the younger Temblor sandstone. Jenkins[8] has made similar observations in the field, and believes further that this "*Leda*" zone correlates with an exposure of like character which he discovered on Domengine Ranch. He says:

> The Leda zone appears to be limited to a few miles in width in the region about Domengine Ranch and in an area north of Arroyo Ciervo. Though very thin and hardly mappable, the beds may represent a formation which once had a greater thickness and extent, for its patchy occurrence would indicate removal by erosion prior to Temblor deposition.

Condit[9] also recognized the presence of this zone, and classified it as the uppermost (or "A") horizon of his four divisions of the "Kreyenhagen."

Below, and in gradational contact with the Tumey shale, is the sandstone of the Tumey formation. This sandstone reaches its maximum thickness of approximately 800 feet about two miles north of Arroyo Ciervo. The upper and major portion of the sandstone consists of massive to poorly bedded, buff-to-brown, usually friable sandstone, with a few limestone lenses and thin layers of ashy shale containing poorly preserved *Foraminifera*. The basal 50 feet or more is composed of coarse, pebbly, dark gray-to-buff-colored sandstone. The pebbles are chiefly of black chert and average less than one-quarter inch in diameter. In some places, this pebbly sandstone is hard and indurated, though usually friable. Near the top of it are the

[8] Olaf P. Jenkins, "Stratigraphic Significance of Kreyenhagen Shale of California," *Mining in California*, Vol. 27, No. 2 (1931), p. 145.

[9] D. Dale Condit, "Age of Kreyenhagen Shale in Cantua-Panoche Creek District, California," *Jour. Paleon.*, Vol. 4, No. 3 (1930), p. 261.

fossiliferous layers from which come species listed in a later paragraph, "II. Tumey Sandstone." Angular-to-rounded shale pebbles and cobbles of varying size (½ inch to 6 inches in diameter), similar in character to the underlying "Kreyenhagen" shale, occur in the lower few feet of the sandstone. The contact with the underlying "Kreyenhagen" is irregular, the top of the "Kreyenhagen" appearing

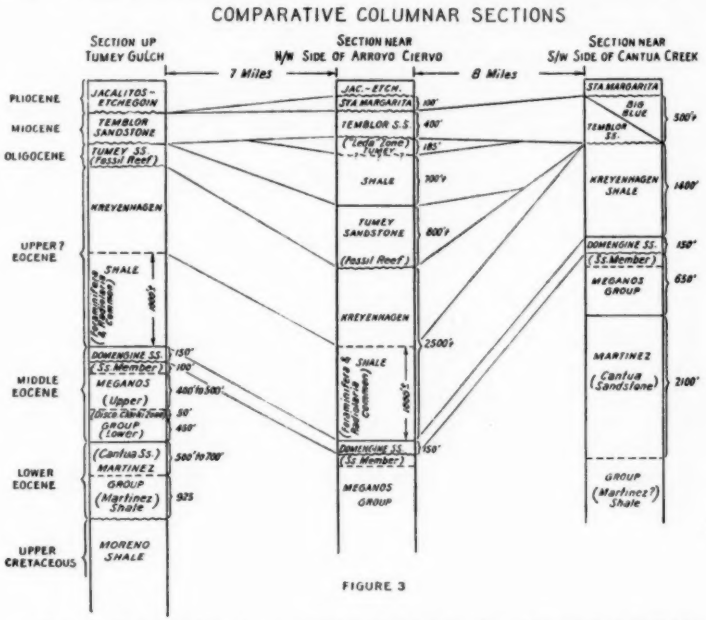

FIGURE 3

FIG. 3.—Comparative columnar sections showing stratigraphic correlation. Thicknesses shown in feet. Solid line indicates conformable contact; wavy line, unconformable contact; broken line, intraformational division.

as an erosional surface. This fact, together with the presence of the basal shale-pebble and cobble conglomerate in the overlying sandstone, constitutes the evidence of an unconformity, though no angular discordance was observed.

The contact of the Tumey formation with the "Kreyenhagen" shale was not traced beyond the point where the Tumey sandstone grades into the Tumey shale, that is, immediately southeast of Arroyo Ciervo. In the general area southeast of Arroyo Ciervo, the Tumey formation is believed to consist entirely of shale in outcrop. It is difficult to identify by lithology because of its similarity in appear-

ance to the underlying "Kreyenhagen" shale; and, furthermore, the proper stratigraphic sequence is in many places obscured by faulting. In the vicinity of Cantua Creek, the Tumey formation can not be observed in outcrop, and only the lower part of the "Kreyenhagen" is exposed (Fig. 3).

The unconformable relationship between the Tumey sandstone and the "Kreyenhagen" shale was noted by both Condit[10] and Jenkins[11] in their publications. The former, in describing his "C" horizon (the writer's Tumey sandstone), says:

> The contact with the underlying "D" beds (the present writer's "Kreyenhagen" proper) is such as to denote an erosion surface with possible angular discordance.

Jenkins mentions the peculiar nature of the contact here, and admits the possibility of an unconformity.

PALEONTOLOGY

PREVIOUS WORK

From the foregoing it is seen that in this region there are present sedimentary rocks aggregating 1,600 feet in maximum exposure, which are traceable for a distance of at least 7 miles, and which are bounded at the top and at the base by unconformities. These strata have been grouped variously with the Vaqueros and the Kreyenhagen, or referred tentatively to the Oligocene. Concerning this last correlation, Clark,[12] in commenting upon fossils collected by John Ruckman[13] from the "upper Kreyenhagen" (the present writer's Tumey shale) of the Domengine Ranch area, tentatively placed all of the Kreyenhagen in the Oligocene because of the genera, strongly suggestive of the Oligocene, discovered in this material. Among these fossils, Clark mentioned

> . . . three typical Lincoln species, *Macrocallista pittsburgensis* Dall, *Leda washingtonensis* Weaver and *Exilia lincolnensis* Weaver, none of which had been found in the Eocene or Miocene.

Later, on being informed by Jenkins of the unconformity at the base of the "upper Kreyenhagen," Clark suggested that

> . . . the name "Kreyenhagen shales" should be retained for the lower shales (the present writer's "Kreyenhagen" proper), and the . . . beds above the

[10] *Op. cit.*, p. 261.

[11] *Op. cit.*, pp. 144, 145.

[12] B. L. Clark, "Tectonics of Coast Ranges, Middle California," *Bull. Geol. Soc. America*, Vol. 14 (1929), p. 760.

[13] John Ruckman, "Faunal Succession of Coalinga East Side Field, Fresno County, California," unpublished thesis at University of California, 1914.

unconformity (the shale of the present writer's Tumey formation) should be given a new name. . . .

On the basis of fossiliferous material supplied by Condit[14] from the diatomaceous shales of his "B" horizon (major portion of the writer's Tumey shale), W. P. Woodring suggested a possible Oligocene age for these shales. The fossils are listed as *Acila* sp., *Pecten* cf. *peckhami* Gabb, *Thyasira* small species, and "*Macrocallista*" small species; and Woodring is quoted as saying:

I know of no Eocene species of *Thyasira* from the Pacific Coast. According to current nomenclature this material would be called Oligocene, but it may be upper Eocene.

PRESENT WORK

I. *Tumey shale.*—The Tumey shale here contains a meager microfauna; but, although the rather poor preservation of much of the material makes exact species determinations difficult, certain definite conclusions may be drawn.

One common form is of the genus *Uvigerina*, and it is thought to be similar to *Uvigerina glabrans* Cushman. It is this form which the writer believes has been mistaken by some recent workers for *U. cocoaensis* Cushman, the common occurrence of which has led them to erroneously apply the name "*Uvigerina cocoaensis* zone" to the whole of the Tumey shale. A careful inspection of the original material collected by Condit[15] from his "B" zone confirms this idea of mistaken identity of the common form of *Uvigerina* which occurs in the Tumey shale. The costae of this form appear to be restricted to the earlier chambers, the later chambers being smooth, whereas on a typical *U. cocoaensis*, the costae extend regularly up to the late chambers of the shell.

The cast of a costate *Plectofrondicularia*, tentatively compared with *packardi* Cushman and Schenck, is also present rather commonly. It was noted that the form occurs with a varying number of costae.

In addition to these two forms, there are present a few impressions of *Bulimina* aff. *sculptilis* Cushman, *Dentalina* and/or *Nodosaria* sp. and an ill-defined rotaloid form.

In only one of the sections which the writer measured, namely, the Arroyo Ciervo section, was the "*Leda*" zone included; and, as previously mentioned, the form "*Leda*" *washingtonensis* Weaver occurs abundantly in the upper 20 feet, approximately, of the shale.

[14] *Op. cit.*, p. 261.

[15] *Op. cit.*, p. 262.

Also casts of "*Pecten peckhami*" Gabb were found, apparently confined to the upper half of the shale.

II. *Tumey sandstone.*—Near the middle of the Tumey sandstone, in a thin interbedded layer of ashy shale, the writer obtained a small faunule of poorly preserved but generically determinable *Foraminifera*. These include the following.[16]

Uvigerina (*cocoaensis* ?)	Common
Bulimina sp.	Common
Gyroidina sp.	Rare
Lagenodosaria (or *Nodogenerina*) sp.	Common
Quinqueloculina sp.	Present
Radiolaria	Abundant

From the fossiliferous zone in the lower 50 feet of the Tumey sandstone, the writer, with the assistance of Hubert G. Schenck, collected a number of megafossils. The following faunal list, prepared with the aid of Mary G. Rathbun, Hubert G. Schenck, Charles W. Merriam, and Leo G. Hertlein, is submitted as evidence to prove the Oligocene age of the Tumey formation.[17]

Acila (*Truncacila*) *shumardi* Dall
Acmaea aff. *dickersoni* Van Winkle
Balanus sp.
Calyptraea sp.
Cardium sp.
Crepidula sp.
Dentalium conradi Dall
Dentalium cf. *radiolineata* Clark
Epitonium sp. indet.
Glycimeris sp.
Lucina sp.
Macrocallista sp.
Mytilus sp.
Ostrea sp.
Pecten aff. *yneziana* Arnold
Polinices (*Euspira*) sp.
Ranidina sp.
Solen sp.
Taras parilis (Conrad)
Thyasira bisecta (Conrad)
Turcicula sp. indet.
Turritella porterensis Weaver n. subsp.
Yoldia aff. *packardi* Clark

In regard to the subspecies of *Turritella porterensis*, Merriam[18] states that he found one of the specimens

> . . . to be in an excellent state of preservation, such that there can be no question as to its identity. It is a form closely related to *Turritella porterensis*

[16] Collecting locality: near center of Sec. 16, T. 16 S., R. 13 E.

[17] Collecting locality: in small unnamed canyon near S. ¼ corner of Sec. 17, T. 16 S., R. 13 E. *Strepsidura lincolnensis* subsp. *lorenzana* Wagner & Schilling was collected recently by D. Birch from the Tumey sandstone. The specimen is No. 986, Schenck collection (Stanford University).

[18] By personal correspondence from Hubert G. Schenck.

Weaver of the Washington Oligocene, perhaps differing from it only subspecifically.

The species is a common one in the Lincoln formation of Washington,[19] but it does not occur in the *Acila gettysburgensis* zone (Blakely formation), or in the Temblor (Miocene), or the Tejon or Cowlitz (Eocene) formations. In addition, it is not known in beds of "Vaqueros" age.

III. *Age of shale below Tumey sandstone.*—The presence of an unconformity at the base of the Tumey sandstone excludes the possibility of a Miocene age, though not entirely the possibility of a Lower Oligocene age, for the "Kreyenhagen" shale below the sandstone. The lower contact of the "Kreyenhagen" shale with the subjacent Middle Eocene (Domengine) sandstone (or Tejon of Anderson and Pack) is, in the writer's opinion, a gradational one. Anderson and Pack[20] indicate a doubtful unconformity, believing that the

> . . . evidence in favor of an unconformity is in part offset by the facts that the two formations appear everywhere conformable in dip, that in many places they seem to grade into each other, and that they are closely associated and almost coextensive throughout this region. . . .

The writer's observations confirm these statements, and this evidence, as well as the paleontologic evidence which follows, seems to outweigh the arguments favoring a profound unconformity at this contact. Jenkins,[21] in describing an area (near old Oil City Camp north of Coalinga) many miles southeast of the district which is being described herein, suggests the possibility of this contact being only a slight break in deposition.

In the shales underlying the Domengine sandstone (these shales having been referred to as "Meganos" by Clark, and as "Martinez?" by Anderson and Pack), the writer discovered a micro-faunule from Cantua Creek to Tumey Gulch, a distance of approximately 12 miles, which establishes the Eocene age of these shales. A partial list[22] of restricted and characteristic species of these shales follows, those species in common with the "Kreyenhagen" being given further on in the paper.

Ammobaculites sp.
Bathysiphon robusta Grazybowsdiego
Bolivina pisciformis Galloway & Morey
Bolivina plicatella Cushman

[19] By personal correspondence from Hubert G. Schenck.

[20] *Op. cit.*, p. 69.

[21] *Op. cit.*, p. 144.

[22] Collecting locality: SE. ¼ of Sec. 11 and NE. ¼ of Sec. 14, T. 16 S., R. 12 E.

Bulimina affinis Cushman
Ceratobulimina alazanensis Cushman & Harris
Chilostomella (*Chilostomelloides*) aff. *cyclostoma* (Rzehak)
Cibicides nucleata (Seguenza)
Clavulina n. sp.
Cyclammina cancellata Brady
Discocylina clarki (Cushman)
Epistomina eocenica Cushman & Hanna
Gaudryina n. sp.
Lenticulina mexicana var. *nudocostata* (Cushman & Hanna)
Nonion umbilicatus var. of Cushman
Planulina wuellerstorfi (Schwager)
Rectobolivina mexicana Cushman

In the lower 1,000± feet of the "Kreyenhagen" between Cantua Creek and Tumey Gulch the writer obtained an assemblage of *Foraminifera*, many species of which are common to the middle Eocene shales below. Some of the more common "Kreyenhagen" forms are here given.

Bulimina inflata Seguenza
Bulimina rostrata Brady
Cassidulina subglobosa Brady
Cibicides aff. *ungeriana* (d'Orbigny) of Galloway & Morey
Eponides aff. *tenera* (Brady)
Lagenonodosaria (or *Nodogenerina*) *monilis* (Silvestri)
Planularia markleyana Church
Robulus welchi Church
Uvigerina gardnerae Cushman n. var. (or *yazooensis* C.)
Uvigerina canariensis d'Orbigny
Valvulineria cf. *pygmea* of Church (not of Hantken)

The following are eight species common to both assemblages, that is, the fauna of the Middle Eocene shales below the Domengine sandstone and that of the lower "Kreyenhagen" shales.

Bulimina inflata Seguenza
Bulimina rostrata Brady
Cibicides aff. *ungeriana* (d'Orbigny) of Galloway & Morey
Gyroidina soldanii d'Orbigny
Lagenonodosaria (or *Nodogenerina*) *lepidula* (Schwager)
Pulvinulinella aff. *culter* n. var.
Robulus inornatus d'Orbigny

This mutual occurrence, or overlap in local stratigraphic range, of the species of *Robulus*, *Cibicides*, and *Pulvinulinella* in the two shales just given suggests an Eocene age for the "Kreyenhagen." This age determination is further strengthened by the fact that a comparison of the "Kreyenhagen" micro-fauna with a representative assemblage from the Keasey shale (lowest West Coast Oligocene) of Washington shows them to be dissimilar. On the other hand, the "Kreyenhagen" fauna bears a pronounced similarity to that of the Coaledo formation (Upper Eocene) of Oregon, which underlies the Bassendorf shale, a correlative of the Keasey shale. To this might be added the statement of Clark,[23]

In the light of the recent discovery by Thos. Bailey of a well preserved Tejon (upper Eocene) fauna in the upper portion of the Markley formation, as exposed in the Potrero Hills north of Suisun Bay, not only must the Markley formation of the Mt. Diablo section be placed in the Eocene instead of the Oligocene, ... but also this makes it probable that the Kreyenhagen shales of the Coalinga area are upper Eocene in age.

Therefore, with a "ceiling" of the Tumey sandstone (Oligocene), an unconformity, and a "basement" of Middle Eocene with gradational contact, and the paleontologic evidence just submitted, there is considerable justification for assigning the "Kreyenhagen," as herein defined, to the upper Eocene, as that term is at present employed in western North America.

CORRELATIONS OF TUMEY FORMATION

The Tumey formation may be correlated with the San Emigdio formation of postulated Oligocene age, as described by Wagner and Schilling.[24] The *Thyasira falgeri* W. & S. (possibly the young form of *Thyasira bisecta* Conrad, as Jenkins[25] suggests) and *Strepsidura lincolnensis* subsp. *lorenzana* W. & S. which occur in the San Emigdio, is the paleontologic evidence upon which this correlation is based. One other mollusk, *Acila shumardi* Dall, appears to be common to both formations.

Jenkins[26] states that *Thyasira bisecta* is also found in the sandstone (officially unnamed) which overlies what he called "the Kreyenhagen proper," west of Wagonwheel Mountain in the Devils Den district. The recent work of D. E. Taylor[27] on the *Foraminifera* of the Wagonwheel Mountain section has indicated the same faunal sequence in the beds between lowermost Miocene and the Kreyenhagen that the writer observed in his sections north of Coalinga. That is to say, Taylor discovered *Uvigerina glabrans* occurring in the shales immediately below the Miocene contact and extending down to the so-called Wagonwheel sand—the probable equivalent of the Tumey sand. Slightly above the conformable contact of these upper shales with the Wagonwheel sand, there occurs an intermingling of both *U. glabrans* and *U. cocoaensis*, while in shale layers of the sand itself,

[23] B. L. Clark, "Tectonics of Coast Ranges of Middle California," *Bull. Geol. Soc. America*, Vol. 14 (1930), p. 760.

[24] C. M. Wagner and K. H. Schilling, "The San Lorenzo Group of the San Emigdio Region, California," *Univ. California Pub., Dept. Geol. Bull.*, Vol. 14 (1923), pp. 237–76.

[25] *Op. cit.*, p. 174.

[26] *Op. cit.*, p. 170.

[27] By oral communication.

as well as in shale beds below the main sand body down to the Kreyenhagen, *U. cocoaensis* predominates. It appears here that the sand member, as in the writer's area, is subject to lateral gradation.

The correlative of the Tumey formation in Oregon is probably the Bassendorf-Tunnel Point group, and probably the Lincoln formation (in part) of Washington.

CONCLUSIONS

The name "San Lorenzo" is inappropriate for the sediments under discussion, because recent work points to the conclusion that the type San Lorenzo may range from Oligocene (or even Eocene) to Miocene in age; and, moreover, because the characteristic San Lorenzo species are not present in the Tumey formation. Furthermore, to refer to the Tumey formation as "Condit's *B* or *C* horizon," or by some similar designation, is obviously unsatisfactory. In short, it seems to the writer that there will be less confusion if a local name be applied.

Therefore, because of its position between two unconformities, with Miocene above and Eocene below, and because of the presence of a diagnostic assemblage of Oligocene fossils, the writer suggests that the name "Tumey formation" be applied to the Oligocene sandstone and shale sequence as described herein—the sandstone to be known as the "Tumey sandstone" and the shale as the "Tumey shale."

The type locality of the Tumey formation is not in Tumey Gulch, unfortunately; but because of the scarcity of available place names in the area, this one was thought to be the best (and practically the only) name that could be used. The type locality is in the south half of Sec. 16, T. 16 S., R. 13 E., Mount Diablo Base and Meridian, Fresno County, California. The sequence of beds is here best determined because of the absence of structural complications.

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PETROLEUM GEOLOGY OF CENTRAL SEDIMENTARY BASIN OF URUGUAY[1]

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ABSTRACT

The Permo-Triassic Gondwana rocks in Uruguay have deficient faunal and floral characteristics, as compared with rocks of the same age in southern Brazil. They are also relatively incomplete stratigraphically. The general shallowness of the sedimentary basin, as seen by surface study and proved by drilling, makes hardly possible the accumulation of oil in commercial amount. It is probable that faults and fractures penetrating most of the sedimentary formations, and many diabases, both intrusive and extrusive, would have come into contact with any oil sands if such had existed underground and would have brought to the surface, either along fracture planes or formational contacts, some indications of the existence of oil, gas, or salt water. This conclusion seems especially reasonable when the shallowness of the sedimentary basin is considered. The same factors and conclusions apply to the Devonian area where the Carmen sandstones and overlying shales are thinly covered by Gondwana sediments and do not reveal any favorable surface indications.

REGIONAL TOPOGRAPHY

The physiographic features of the Permo-Triassic Gondwana rocks of the central and northern parts of Uruguay represent a rather even rolling country, with characteristics of a very mature peneplain.

The sedimentary basin, which is a continuation of the wide belt of Gondwana sediments of southern Brazil, extends in Uruguay through the departments of Rivera, Tacuarembó, Cerro Largo, and northeast Durazno, occupying a total area of approximately 25,000 square kilometers.

Besides the table lands which are typical features in the erosion of the Gondwana rocks, there are many dome-shaped hills, most of

[1] Manuscript received, April 15, 1935. Published by permission of the director, Department of Mines of Brazil.

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This paper is based on the latest investigations of the Geological Survey of Uruguay, the most recent field observations of several geologists, and on the writer's personal acquaintance with the geology of the country and his studies of many well logs and cores.

The writer is particularly indebted to Djalma Guimarães, director of the Department of Mines of Brazil, for collaboration and for permission to publish this paper; to E. Terra Arocena, director of the Instituto de Geologia e Perforaciones of Uruguay for many unpublished data of recent geological investigations and for his kind permission to study the cores and logs of most of the deepest wells in Uruguay. The writer is also indebted to J. Falconer for much useful and interesting information, and to Alvaro de Paiva Abreu for help in the preparation of this paper.

FIG. 1.—Map showing areal geology of Uruguay and location of principal test wells.

which are due to batholithic masses or to the proximity of the crystalline basement.

The greatest part of the area does not exceed the average elevation of 100–150 meters, though on the Uruguay-Brazilian border the elevations are locally as great as 250 meters above sea-level.

The central and southern parts of the basin are drained by Tacuarembó River and its tributaries, and the southern part is drained by the valley of Rio Negro.

The Serra Geral, a basaltic elevation of approximately 700–900 meters, which extends more than 1,000 kilometers north and south through southern Brazil, continues southward as a wide plateau in Uruguay with an east-facing escarpment 250–300 meters high, extending as a wide trap plateau west of the sedimentary basin. The basalts gradually dip southward and disappear beneath Cretaceous sediments in the valley of Rio Uruguay.

REGIONAL GEOLOGY

The sedimentary basin is sharply defined on its eastern and southern margins by the metamorphic and crystalline rocks of the Basement complex, and, as has been stated, by the basaltic traps of the Serra Geral on its western margin. On the north the basin continues into Brazil.

So far as petroleum geology is concerned, this seems to be the only area in Uruguay in which possibly favorable rocks are present and accessible at the surface. The strata of interest above the Basement complex include the Lower Devonian, Lower and Upper Permian, and Upper Triassic formations. The Basement complex, which immediately underlies the Lower Devonian and Triassic flows, and the irregularly developed terrestrial sandstones of Cretaceous age at the top of the section have evidently no significance as possible oil-bearing horizons.

PERMO-TRIASSIC FORMATIONS

The exact limits of the Permo-Triassic formations at the east extend along the broad belt of Algonkian and Archean metamorphic rocks which form the remaining eastern and southern parts of the country. The contact line extends from Paso Manuano, on the border of Brazil, toward the southwest, lying about 15 kilometers south of Melo and Fraile Muerto, and crossing the headwaters of Arroyo Cordobez farther west.

The western contact with the Triassic traps of the Serra Geral extends approximately along the railroad from Rivera to Tacuarembó,

TABLE I*

STRATIGRAPHIC COLUMN OF URUGUAY

Era	*System*	*Formation*	*Description*	*Correlation With Southern Brazil*
	Recent and Pleistocene		Alluvial sands, clays, and gravels; valley-fill and sea sands	
Mesozoic	Lower Cretaceous		Light-colored coarse clays and sandstones, forming extensive beds in the valley, mainly of Rio Uruguay	Baurú sandstones
Mesozoic	Upper Triassic or Jurassic(?)	Serra Geral traps	Lava flows of diabases and melaphyres covering western half of country. Continuation of trap area of southern Brazil	Serra Geral traps
Mesozoic	Upper Triassic	Tacuarembó sandstones	Clear or red coarse sandstones mainly of æolian deposition. May enclose some beds of aqueous origin	São Bento series Botucatú and Riodo Rasto beds
Mesozoic	Upper Triassic	Estrada Nova beds	Red sandy shales, interbedded with layers of red or greenish clays. Characterized by a lamellibranch fauna of *Terraia altissima*	Upper Passa Dois series. Upper Estrada Nova beds
Paleozoic	Upper Permian	Melo beds	Dark gray and black clay shales; remains of *Mesosaurus brasiliensis* and of *Stereosternum tumidum*	Lower Estrada Nova and Iraty beds
Paleozoic	Lower Permian	Palermo beds	Gray or light-colored, horizontal sandstones	Tubarão series. Palermo beds
Paleozoic	Lower Permian	Bonito-Itararé beds	Gray sandstones and clays of glacial origin, with tillites and striated boulders	Rio Bonito beds and Itararé formation
Paleozoic	Lower Devonian	Devonian shales	Micaceous, dark gray shales, very fossiliferous. Fauna of *Leptocoelia flabellites*, *Chonetes falklandicus*, spirifers, etc.	Ponta Grossa shales
Paleozoic	Lower Devonian	Carmen sandstones	White quartzitic sandstones. Not fossiliferous	Furnass sandstones
	Algonkian to Archean	Basement complex	Gneiss, granites, phyllites, and other crystalline and highly metamorphic rocks	Basement complex

* This table, as conceived by the writer, may have its nomenclature of the formations in Uruguay slightly altered, since the Cretaceous beds and Devonian shales have not yet received proper names in this country.

deviating east of it in the Department of Tacuarembó and lying near San Gregorio in the valley of Rio Negro.

The southernmost limits of this basin are formed by a rather

narrow area of Devonian sandstones, typically exposed at the locality of Carmen.

Much of the southern part of the basin shows well developed glacial Permian formations of the Bonito-Itararé series. (The Uruguayan geologists do not separate the two horizons as belonging to different formations, as Itararé and Tubarão of the Santa Catharina system in Brazil.)

The tillites and glacial boulders with characteristically striated surfaces crop out here and there in some localities of the area.

The higher member of the Tubarão series, consisting mainly of gray sandstones and sandy shales, forming the Palermo beds, borders the northern limits of the glacial formations. Superposed apparently conformably are black and dark gray shales with some scarce remains of the *Mesosaurus brasiliensis* and *Stereosternum tumidum* fauna. This bed of Upper Permian age is known as "Melo," and evidently corresponds with the Iraty beds and the Lower Estrada Nova beds of southern Brazil, of which it is a logical continuation.

The Melo horizon contains the red and variegated shales of the Estrada Nova beds of Uruguay, corresponding with the upper part of the Passa Dois series of Brazil.

Bituminous shales and limestones, so common in the Iraty beds of Brazil, are extremely rare in the Melo of Uruguay.

The general character of the Melo and its incomplete development, as compared with the Iraty, suggest its deposition in lacustrine or edge-water conditions. The greatest horizontal and vertical development of the Melo beds is attained in the Department of Cerro Largo.

The variegated shale beds of the Estrada Nova cover the northern part of the Department of Rivera, extending across the border into the State of Rio Grande do Sul in Brazil.

With the exception of numerous fragments of petrified wood, no fossil remains were found in these beds. The fragments of wood have not yet been paleobotanically classified, due to the excessive silicification of the vegetable fibers and cells.

Mention should be made of an *Estheria* recently found by J. Keidel near Calera in the Department of Rivera. The fossil has been shown to the writer by Terra Arocena, but not yet classified.

The characteristic, continuous chert layers, so common in the same formation in southern Brazil, are unknown in the Estrada Nova beds of Uruguay. Also, the Rocinha limestones of the upper part of the Passa Dois series, which occur in the State of Santa Catharina in Brazil, are not known in Uruguay.

The largest part of the western border of the basin is formed by the Tacuarembó sandstones. They are red, or cream-colored sandstones, of a fine-to-very-coarse texture, false-bedded, overlying, or in places interbedded with, layers of clay stones. This formation is correlated with the São Bento series and the Botucatú and Rio do Rasto beds of southern Brazil. In the Tacuarembó beds, near the locality of the same name, were recently found fossil remains of a ganoid fish, described by Walther as *Seminotus* or *Lepidotus*, probably of Neo-Mesozoic age; the fossil remains appear, however, to be insufficient for an exact classification of the species.

Some gastropods were also recently found in the same region. According to their stratigraphic position, these remains of a marine fauna correspond with the Botucatú and Rio do Rasto beds of Brazil. This relation obviously contradicts the existing conception of an æolian origin of the Botucatú sandstones, proving, rather, that aqueous facies were present in the deposition of the equivalent Tacuarembó beds in Uruguay.

The Tacuarembó sandstones seem to lie unconformably above the Bonito-Itararé in the southwestern extremity of the area, and above the Estrada Nova beds, forming an isolated patch south of Buena Vista in the Department of Cerro Largo; they form a contact *en dents de scie* with the basaltic trap of the Serra Geral at their western limits.

Fossil remains of the saurian *Scaphonix fischeri*, so characteristic of the Rio do Rasto beds of southern Brazil, particularly in the State of Rio Grande do Sul, are not known in Uruguay.

Lamellibranchs, *Terraia altissima*, were recently found in the Department of Rivera near the locality of Hospital; they were found on top of a much-eroded outcrop of Palermo beds. Despite the existing slight confusion in the classification of the mollusks of Hospital, the writer believes that they belong to the same genus as *Myophorias* and *Myophoriopsis*, found in Canoinhas, Serrinha, and Theresina, in southern Brazil, and described by Cowper Reed. The species belong to the Upper Estrada Nova beds of Triassic age, being marine in origin.

In the southern part of the Department of Rivera a large mass of the crystalline basement rocks is exposed in the midst of the sedimentary area. The contacts with the Estrada Nova beds at the north and the Palermo beds at the south reveal extensive faulting, probably of post-Permian time. The sedimentary and crystalline rocks in the Sierra de Acegua in the Department of Cerro Largo show similar faulted contacts.

The intrusive diabases in different forms of batholiths, dikes, sheets, et cetera, are very plentiful in the basin. Intrusives of an andesitic character form several outcrops in the southeastern part of the area.

The trap plateau occupies almost the entire western half of the country. This trap rock is found also by drilling in the Province of Entre Rios in Argentina evidently as a continuation of the same formation. Only in the valley of Rio Uruguay are these traps covered by irregularly developed Cretaceous sandstones and clays. At the boring of Paso Ulestie, in the Department of Rio Negro, these sedimentary rocks have a thickness of 260 meters, overlying a melaphyre and diabase sheet 360 meters thick.

DEVONIAN FORMATIONS

The southernmost limits of the sedimentary basin are formed by a narrow strip of coarse white sandstones, typical at the locality of Carmen. In the Department of Durazno, the outcrop extends from approximately Faruco at the northeast to Carmen at the southwest.

The Carmen sandstones were until lately assigned by the local geologists to the glacial Bonito-Itararé horizon of Permian age. The writer's previous extensive studies of a wide area of proved Devonian rocks in the State of Paraná in Brazil enable him to identify positively the Carmen sandstones with the equivalent Furnass sandstones of Paraná in Brazil, both being of undoubted Devonian age because of their lithologic character, their stratigraphic position, and correlation with overlying fossiliferous beds.

A test boring at Rincon de Alonso, in the valley of Rio Negro, north of the outcrops of Carmen sandstones, revealed, beneath 25 meters of Bonito-Itararé sediments, a horizon of Ponta Grossa Devonian shales, with a typical and well represented austral fauna of brachiopods, *Leptocoelia flabellites*, *Chonetes falklandicus*, et cetera.

The existence in Uruguay of a Devonian fauna and the Ponta Grossa shales was discovered and acknowledged by E. Terra Arocena in 1926. The recognition of the Carmen sandstones as Devonian and their identity with the Furnass sandstones of Brazil were first mentioned by the writer in a paper presented to the Brazilian Academy of Sciences.[3]

With the addition of the Carmen sandstones to the already known Ponta Grossa shales, there is actually established the almost com-

[3] Victor Oppenheim, "Sobre a bacia sedimentaria Gondwanica da Republica do Uruguay," *Annaes da Acad. Bras. de Sci.*, Vol. VI, No. 3 (Rio de Janeiro, September, 1934).

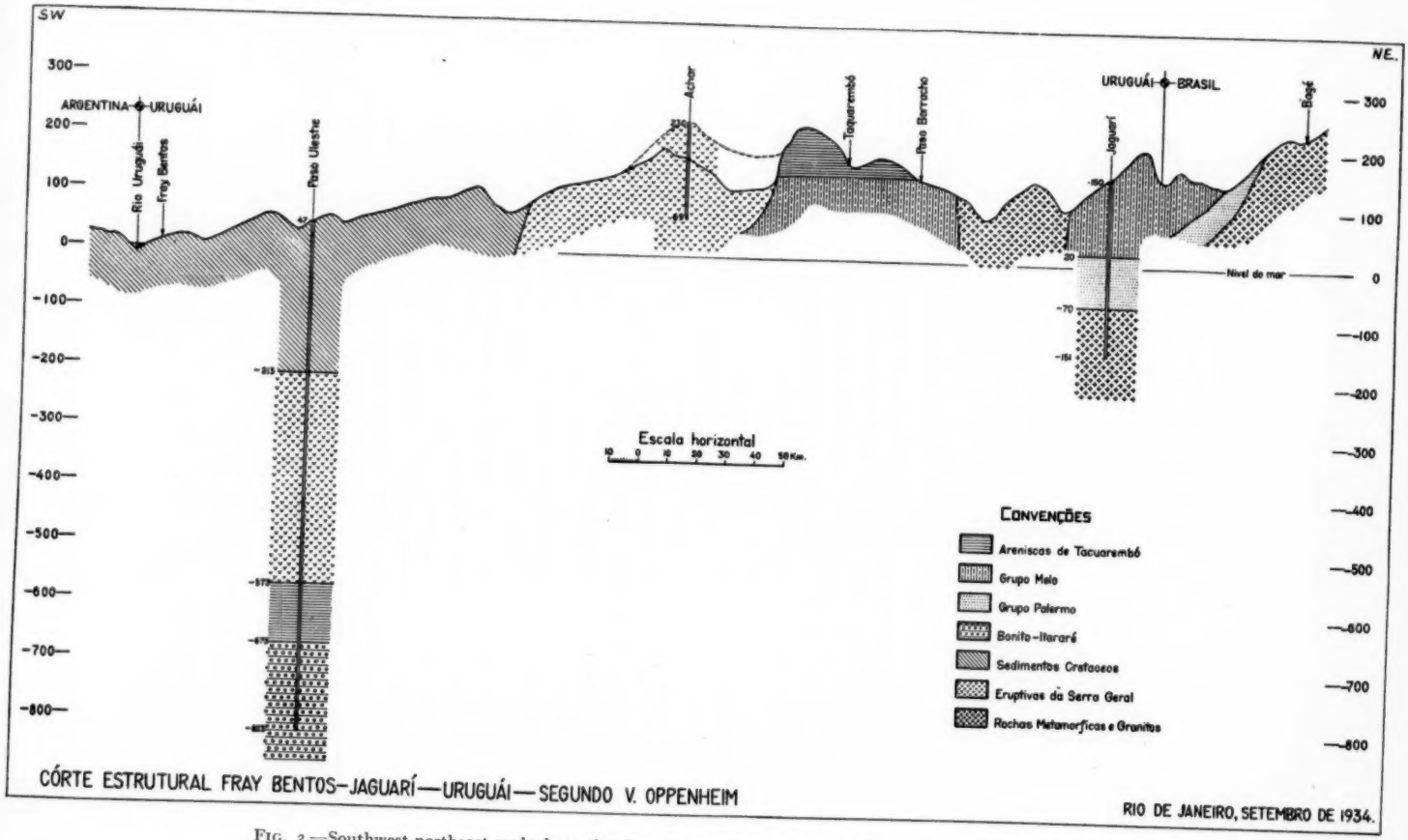

FIG. 2.—Southwest-northeast geologic section from Fray Bentos to Jaguarí, Uruguay. Vertical scale in meters.

plete sedimentary column of the Lower Devonian formation, as known in the Paraná basin, in Brazil.

The cores of the La Paloma test well, now being drilled, clearly demonstrate that, below 100 meters of tillitic Bonito-Itararé sediments, there are fossiliferous, dark gray, micaceous Ponta Grossa shales, thus showing that the Devonian rocks occupy a definite area below the Permian sedimentary cover. However, the tests farther north of the area did not reveal the presence of Devonian beds below the Gondwana sediments, several borings, for example, the Jaguarí and Paso Boracho tests, having reached the crystalline Basement complex, without finding them.

The widely separated outcrops of Lower Devonian formations, for example, those in Uruguay, those in the State of Paraná and the State of Mato Grosso in Brazil, and those in Paraguay, confirm the fact that the outcrops are not connected in a continuous bed across the Paraná basin, as some authors were inclined to believe, but rather they appear as isolated patches unconformably overlying the Basement complex, similar in occurrence to the Devonian outcrops of Uruguay.

TECTONICS

Most of the sedimentary basin shows evidence of an extensive inter-Gondwana erosional unconformity. This is particularly exposed at the southwestern limits of the area, where the Neo-Gondwana Tacuarembó beds and the Triassic traps of the Serra Geral overlap the Lower Permian Bonito-Itararé with considerable stratigraphic break. A deep erosional effect is also seen in the central area of the basin, as shown by the protruding and locally striated outcrops of basement granites, surrounded and transgressively superposed by the Upper Estrada Nova beds of Triassic age.

There is much evidence of intense diastrophic movements that affected Uruguay during the great Triassic diastrophism of the entire Paraná basin. The older Permian sediments appear to be more disturbed by faulting and fracturing than the younger Triassic rocks capping them; this impression, however, may be caused by the intense erosion and prolonged process of peneplanation which may have concealed the fault planes and escarpments of the Triassic rocks. Faults were observed in many contact areas with the basement rocks, as in the northeast part of the basin and at Cerro Chato in the Department of Tacuarembó, between the Bonito-Itararé and the Estrada Nova beds.

Confirming the observations in the Paraná basin in southern

FIG. 2.—Southwest-northeast geologic section from Fray Bentos to Jaguarí, Uruguay. Vertical scale in meters.

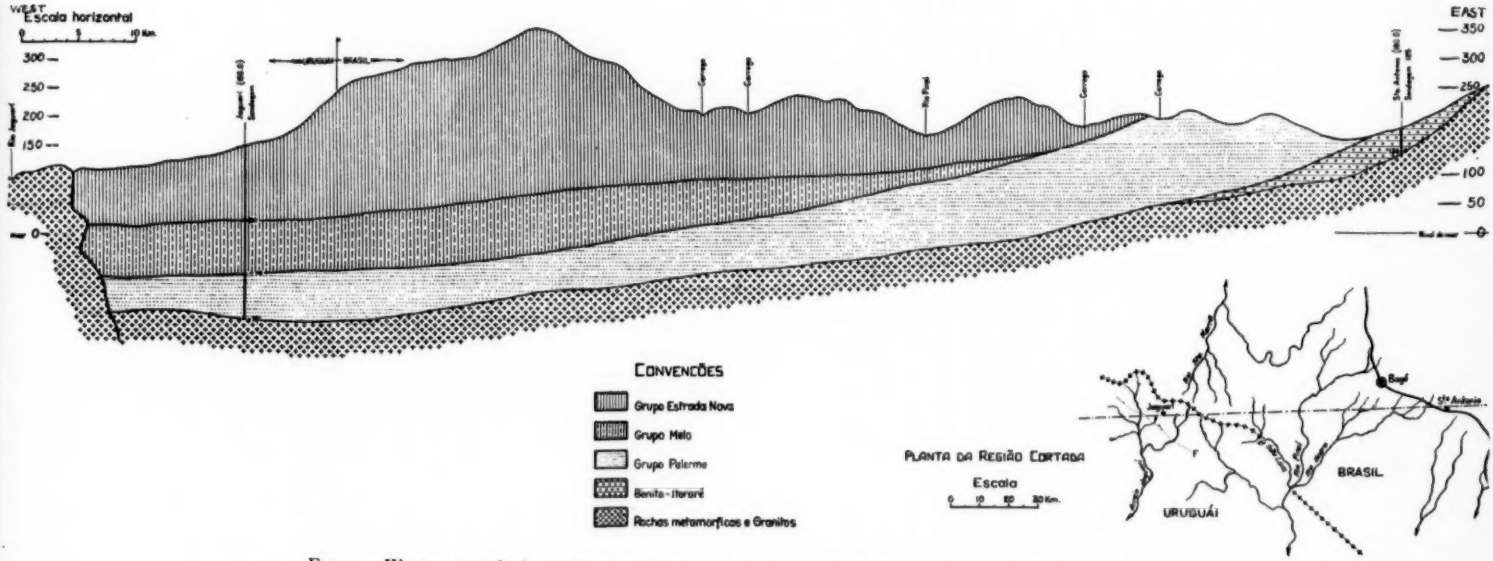

FIG. 3.—West-east geologic section from Jaguarí, Uruguay, to San Antonio, Brazil. Vertical scale in meters.

Brazil, the gradual lowering of the basaltic trap bed from the elevated escarpment of the Serra Geral westward is not caused by a regional western dip of the bed, but rather by a succession of *en échelon* faults downthrown toward the west. The amount of the downthrow can be deduced by comparison of the position of the trap beds at 213 meters below sea-level in the Paso Ulestie boring with the position of the trap at 250 meters above sea-level at the escarpment of Serra Geral in the Department of Tacuarembó, thus showing a difference in elevation of 463 meters in a distance of approximately 220 kilometers.

Smaller faults and fractures, generally associated with the extensive intrusive bodies, are common in the basin.

The structural features of dislocation seem to be characteristic of the Gondwana formations of the whole Paraná basin, including Uruguay. Folding, due to tectonic forces, has not been observed in the sedimentary area of Uruguay; this is well shown by the great areas of horizontal strata, with a few very local dips, generally caused by the intrusive bodies of diabases.

J. Falconer has informed the writer of some anticlinal folds observed by him in the eastern part of the Department of Cerro Largo; according to him, they were produced by the compression of the Bonito-Itararé beds between crystalline basement masses, due to an isostatic movement of apparently recent date.

The thickness of the complete sedimentary column of the Permo-Triassic system, according to Falconer, is 600 meters. The maximum thickness of the entire sedimentary column of Devonian-to-Triassic sediments of the basin, including the formations from the base of the Carmen to the top of the Tacuarembó sandstones, but not including the basaltic traps, does not exceed approximately 800 meters. The average thickness of the basaltic traps may exceed 300 meters.

MAIN TEST WELLS

Through the courtesy of Terra Arocena, the writer was able to study many cores from test wells in different parts of the country, drilled during the last few years or now being drilled.

Approximately 35 wells have been drilled in the sedimentary basin, either for study or in search of oil. At the time of the writer's stay in that country, the deepest well in Uruguay, at Paso Ulestie, drilled with long interruptions, reached 870 meters. According to a letter from Terra Arocena, dated November, 1934, the boring had reached 910 meters.

Most of the other wells are relatively shallow, the deepest hardly reaching 400 meters, though many have reached the Basement com-

plex at much less depth. At Paso Boracho, Jaguarí, and Carmen, the wells entered the basement rocks at depths of 310, 301, and 110 meters, respectively, thus proving the average shallowness of the basin in rather widely separated localities.

At present, three wells are being drilled for research purposes: at Paso Ulestie in the Department of Rio Negro; at Cañada de los Burros in the Department of Cerro Largo; and at La Paloma in the Department of Durazno.

The Paso Ulestie well, after having drilled through the basaltic and melaphyre trap from 260 to 620 meters, drilled to 720 meters through the Tacuarembó beds, and at the depth of 910 meters was drilling in the Bonito-Itararé formation.

The Cañada de los Burros well was drilling at 270 meters, in the Bonito-Itararé.

The La Paloma well, after first penetrating 100 meters of the Bonito-Itararé, was penetrating the Ponta Grossa Devonian shales.

Several other wells, though of less geological interest, are being drilled in different parts of the sedimentary area.

Most of the wells are drilled with rotary Calix-Davis equipment, which seems satisfactory for shallow drilling in sedimentary rocks, but very slow for drilling the numerous diabase intrusions.

PETROLEUM POSSIBILITIES

Petroleum has not been found in Uruguay. No active seepages are known, and no showings of oil or gas were observed in the many test wells.

The occurrence, here and there, of the very slightly bituminous shales of the Melo horizon has no significance as an indication of possible oil-bearing sands. These shales are the continuation of the considerably more developed Iraty shale horizon of Brazil, which has been already proved unimportant as an oil-bearing horizon.

The bituminous impregnations in the Tacuarembó sandstones in the Department of Rivera are similar to, though smaller than, the well known impregnation in Bofete, São Pedro, and many other localities in the State of São Paulo, Brazil. They are probably due to deposition by the circulating subsurface waters of the Iraty beds (Melo in Uruguay). The impregnations are commonly observed around, or in contact with, intrusive diabases, where the fracture planes opened ways of circulation for the underground waters, thus explaining the deposition of bituminous material in the sandstones of Upper Triassic formations.

TABLE II

LOGS OF MAIN TEST WELLS IN URUGUAY

Formations	*Depth in Meters*	*Elevation in Meters, Sea-Level Datum*	*Thickness in Meters*
Paso Ulestie well, Department of Rio Negro. (Incomplete)			
Derrick floor		47	
Cretaceous sediments	260	−213	260
Basaltic trap	620	−573	360
Rio do Rasto beds (?)	720	−673	100
Melo (Estrada Nova)	870	−823	150
Palermo beds	910	−863	40
Achar well, Department of Tacuarembó			
Derrick floor		230	
Intrusive diabase	161	69	161
Bonito-Itararé formation			
Tambores well, Department of Tacuarembó			
Derrick floor		270	
Intrusive diabase	170	100	170
Paso Boracho well, Department of Tacuarembó			
Derrick floor		120	
Palermo beds	150	− 30	152
Bonito-Itararé	302	−182	152
Granites of Basement complex	310	−190	8
Jaguarí well, department of Rivera			
Derrick floor		150	
Estrada Nova	130	20	130
Melo	220	− 70	90
Palermo beds	301	−151	81
Basement complex			
Cañada de Los Burros well, Department of Cerro Largo. (Incomplete)			
Derrick floor		120	
Melo and Palermo beds	270	−150	270
Bonito-Itararé			
Fraile Muerto well, Department of Cerro Largo			
Derrick floor		120	
Palermo beds	178	− 58	178
Bonito-Itararé	191	− 71	13
La Paloma well, Department of Durazno. (Incomplete)			
Derrick floor		130	
Bonito-Itararé	100	30	100
Devonian shales, fossiliferous beds			
Carmen well, Department of Durazno			
Derrick floor		140	
Cretaceous (?)	10	130	10
Carmen sandstones	110	20	100
Basement complex			
Capella Farruco well, Department of Durazno			
Derrick floor		150	
Carmen sandstones	79	71	79

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VOL. 19, NO. 8 (AUGUST, 1935), PP. 1219-1225, 4 FIGS.

APPARENT RECENT CRUSTAL MOVEMENT AT WESTERN END OF OUACHITA MOUNTAINS, OKLAHOMA[1]

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ABSTRACT

Water and sewer mains installed in 1906 and 1913, respectively, along east-west streets on the east side of a northward-trending ridge in Atoka, Oklahoma, have given trouble by breaking repeatedly at the points where they cross the outcrop of one of three steeply inclined thick sandstone beds that support the ridge. The points at which the ruptures occur are disposed along a straight line. At one of these points a main was reported to be offset 4 inches, the displacement being horizontal and in the direction of alignment. It appears, therefore, that the phenomena are due to faulting, though no earthquakes have been felt in the immediate neighborhood.

As presented to the writers, the evidence of recent crustal movement in the vicinity of Atoka, Oklahoma, consisted of (1) discrepancies between recent and earlier surveys, (2) misalignment of east-west sidewalks on the east side of a ridge in the western part of the town, (3) movement of the buttresses and piers of the Missouri, Kansas and Texas Railroad bridge at North Boggy Creek, 4.5 miles northeast of Atoka, and (4) rupture of water and sewer lines running normal to the ridge along east-west streets, and cracks in the foundations of several buildings in the western part of Atoka. The first three of these lines of evidence had to be discarded either because of insufficient data or because the observed phenomena could be explained satisfactorily by causes other than crustal movement. The evidence afforded by breaks in the water lines and sewer mains, however, seemed convincing to the writers.

Most of the data presented herein were collected by the writers at Atoka in October, 1934, and February, 1935. Their attention was directed to the phenomena by E. C. D'Yarmett, a petroleum engineer, of Atoka. The writers are indebted to D'Yarmett for guiding them to points at which the evidence was observed and they wish to acknowledge his coöperation and that of officials of Atoka and of the

[1] Published by permission of the director of the United States Geological Survey. Manuscript received, May 27, 1935.

[2] United States Geological Survey.

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Missouri, Kansas and Texas Railroad in furnishing pertinent information.

The principal localities to be described lie in the town of Atoka, near the western end of the Ouachita Mountains and close to the Choctaw fault, as shown in Figure 1. The surface rocks west of the

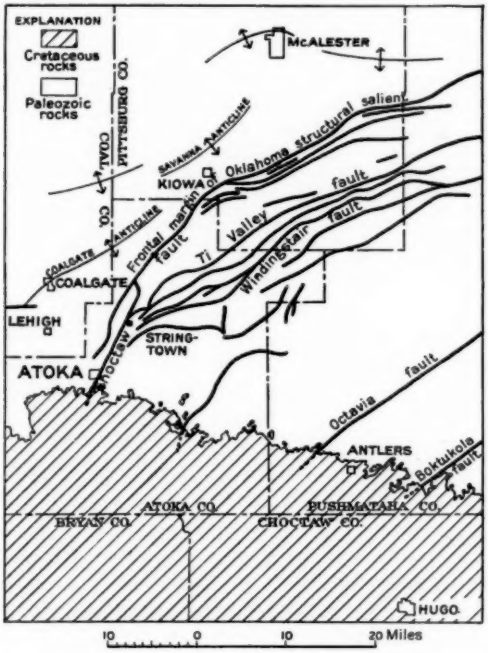

FIG. 1.—Geologic map of part of southeastern Oklahoma.

Choctaw fault in the immediate vicinity of Atoka belong to the Atoka formation, of Pottsville (early Pennsylvanian) age. The rocks of this formation in a belt 1–3 miles wide, bounded on the east by the Choctaw fault and extending from Atoka northeastward to Stringtown, were examined during the present investigation and were observed to be broken by several faults approximately parallel with the Choctaw fault.

Alternating shales and conglomeratic sandstones of the Atoka formation form a ridge about 70 feet high in the western part of Atoka. The topography of this ridge and the areal distribution and

attitude of the rocks that compose it are shown in Figure 2. The stratigraphic sequence of the rocks exposed on the ridge is shown in Figure 3.

The water system of Atoka was installed in 1906; the sewer systems in 1913. The extension of the mains to the ridge in the western part of the town was made at a somewhat later date. Ever since their

FIG. 2.—Map of part of Atoka, Oklahoma.

installation, the east-west water mains have shown recurrent leaks at the points indicated in Figure 2. These leaks were caused by loosening of the joints and were repaired before complete failure resulted.

At locality 1 (Fig. 2), 60 feet west of the intersection of A Street and Montana Avenue, a 6-inch tile sewer pipe was buried in a trench running along A Street. This trench is about 10 feet deep and just wide enough at the bottom to admit the pipe. For 5 or 6 years prior to 1933 this sewer pipe was subject to repeated stoppage and it be-

came increasingly difficult to run cleaning rods through the pipe from the man-holes at the intersections of A Street with Montana and Minnesota Avenues. In June, 1933, the pipe was uncovered at the point indicated and was inspected by E. C. D'Yarmett at the request

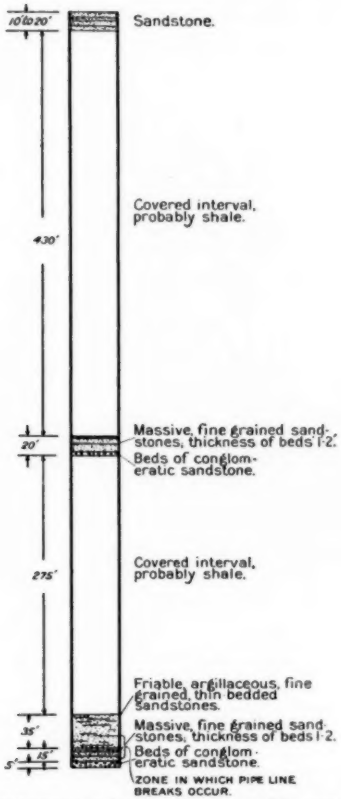

FIG. 3.—Columnar section of rocks exposed in western part of town of Atoka, Oklahoma. Thickness in feet.

of the foreman in charge of repairs. Although the pipe had not been moved by the workmen, it was found to be broken and offset, the portion of the pipe southeast of the break being offset northward relative to the portion northwest of the break. A similar offset was observed in the walls of the old trench, which at this point had been dug through the friable sandstones overlying the lower conglomeratic

beds. The tile was sheared at right angles to its longitudinal axis, and its crumbled ends were in contact. The direction of the shearing was therefore parallel with Montana Avenue, which runs N. 20° E., and coincides with the alignment of all the points of breakage along the ridge. The displacement was entirely horizontal and amounted to 4 inches.

At locality 2 (Fig. 2), near the intersection of Court Street and Montana Avenue, the 4-inch water main along Court Street had to be repaired three times during 1933 at a point where it passes through the lower conglomeratic beds. The stone foundation of the house at the southwest corner of this intersection has been so badly distorted that portions of it have had to be replaced or repaired three times

FIG. 4.—Cracks in concrete foundation of house at locality 4. Looking northward.

since the house was built, and cracks in the foundation were noted at the time of the examination.

The brick schoolhouse, which stood at locality 3 (Fig. 2), at the intersection of First Street and Minnesota Avenue, before it was destroyed by fire in 1934, showed two cracks in the west half of the building, one in the north wall and the other in the south wall. Both cracks extended from the roof to the base of the foundation and were in approximate alignment with the axis of the ridge. The rocks at the building site show considerable variation in amount of dip and some thin sandstone beds dip steeply southeastward.

The small frame bungalow at locality 4 (Fig. 2) is set on a poured concrete foundation which averages 3 feet in height, is 12 inches thick at the base and 8 inches thick at the top. Such a foundation would normally be more than adequate to support the house, yet it is badly cracked, as shown in Figure 4. At least one break in the sewer pipe

has occurred in front of the house and there have been numerous leaks in the water main at a point about 100 feet east. Similar trouble was experienced at Third Street and at Fourth Street at the points indicated in Figure 2.

The apparent conclusion to be drawn from these data is that movement has taken place since 1906 in the rocks composing the ridge. The following observations seem to support the view that the movements are due to faulting.

1. Actual offsetting of the sewer pipe at locality 1 was observed.

2. The seven points at which the east-west pipes have given trouble lie nearly in a straight line.

3. The direction of movement along a line bearing about N. 20° E., as indicated by the broken sewer pipe at locality 1 and by the alignment of all the breaks in water mains and sewers, coincides with the strike of the steeply tilted beds on the ridge and approximately parallels the traces of the Choctaw fault and of several minor faults near Atoka. It is therefore known to be a direction of structural weakness in this neighborhood.

The movement is probably more or less continuous rather than intermittent, because earthquake shocks have not been felt in the neighborhood and because rupture does not happen simultaneously in all the pipes, but occurs at different times. It is believed that the strain that brings about failure of a given pipe accumulates slowly until the ultimate strength of the pipe is exceeded and that failure then takes place suddenly.

The distortion and cracking of the foundations of several buildings on the ridge and the necessity for frequent readjustment of door and window frames in these houses may be related to the same disturbance. Buildings in other parts of the town are relatively free from such troubles, though the quality of their construction appears to be no better than that of the buildings on the ridge.

It is believed that no alternative hypothesis offers a satisfactory explanation of the facts that have been presented. The breaks in the mains, which are buried under several feet of soil, could not have been caused by freezing, because the climate of this region is so mild that the frost never penetrates more than a few inches below the surface. The absence of thick limestone or other soluble beds near the surface and the fact that the movement is horizontal preclude the explanation of slumping due to underground caverns. It appears improbable that hillside creep of the strata can account for the movements, inasmuch as the direction of a horizontal component of motion due to hillside creep would presumably be normal to the trend of the

ridge rather than parallel with it. Moreover, the ridge is supported by three competent sandstone beds and the maximum grade of the shale slope on the east side of the ridge, where most of the movement has been observed, is only about 6°.

The Texas-Oklahoma earthquake of April 11, 1934, which was felt at Hugo, Oklahoma, is regarded by Sellards[4] as due to movements on old faults in the Balcones fault zone. These movements and the movements at Atoka may be indicative of widespread crustal mobility at the present time in the Ouachita belt. That this region has been characterized by instability during much of the geologic past is known from (1) the immense thickness of the Paleozoic rocks exposed in the Ouachita belt, which aggregates about 30,000 feet, (2) the numerous unconformities, flexures, and faults in these rocks, (3) the northward incursions of the sea into this and near-by regions during the Cretaceous and Tertiary, and (4) the deformation of the Cretaceous rocks in the adjacent parts of the Gulf Coastal Plain.

[4] E. H. Sellards, "Texas-Oklahoma Earthquake of April 11, 1934," *Geol. Soc. America*, preliminary list of titles and abstracts of papers to be offered at the 47th annual meeting, 1934.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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GEOLOGICAL NOTES

DISCOVERY OF OIL AND GAS IN MERCEDES FIELD, HIDALGO COUNTY, TEXAS

The Mercedes prospect, now designated as the Mercedes field by the San Antonio Geological Society's committee on field names, was proved to have oil and gas on the night of April 9, 1935, when the Union Sulphur Company's American Rio Grande Land and Irrigation Company's No. 3 flowed 500 barrels of wash water with 20 per cent 49.2° gravity crude and a volume of gas estimated to be 34 million cubic feet according to scout reports. Pressures increased to 2,250 pounds on tubing and 2,500 on the casing. Casing was set at 7,477 feet and the total depth was 7,499 feet. A shale "break" is said to occur in the sand section. An unconfirmed report places the age of the producing sand as Frio.

On account of trouble with the screen, which seemed to have been cut by the flow of fluids, the well was "killed," the screen replaced and, on April 29, scout reports gave the production as 185 barrels of oil flowing through two ⅛-inch chokes with a pressure of 750 pounds per square inch on the tubing and no pressure gauge on the casing.

The well is now flowing its prorated allowance of 150 barrels of oil of about 58° gravity, with about 2,000 cubic feet of gas per barrel of oil, the tubing pressure being 850 pounds. A recent test indicates a rate of 200 barrels per day as the most economic rate of production for this well when flowing through a ⅛-inch choke orifice.

Two earlier wells drilled by the Union Sulphur Company had been abandoned without tests for oil and gas having been made, other than the taking of cores and making of electrical hole surveys. The first well was abandoned at 6,431 feet because of mechanical trouble. The second well, located about 100 feet southeast of the discovery well, had been drilled to 8,044 feet, at which depth drilling was abandoned and an attempt made to test 12 feet of "broken sand" reported between 7,500 and 7,600 feet. At 7,376 feet an attempt was made to cut out through the casing wall to drill a new hole, but the drilling pipe stuck and could not be entirely removed, which accident resulted in the abandonment of the well and the location of the No. 3, the discovery well, about 100 feet farther northwest.

This discovery of oil and gas in southeastern Hidalgo County, is 30 miles east of the Sam Fordyce, the nearest previously developed

pool, which lies in the southwestern part of the same county. The Mercedes discovery was 55 miles from the nearest oil or gas production on the United States side of Rio Grande at the time drilling was begun, and 75 miles from the nearest field at an equal distance from the coast line, the Kingsville pool, Kleberg County. For these reasons the method of its discovery may be of interest to *Bulletin* readers.

In July, 1933, Tom F. Nolan of Mercedes, who has followed the oil business for a number of years, reported to Burton McCollum that he had seen seepages of gas over an area of an acre or more in the North Floodway of Rio Grande delta during a flood caused by a tropical cyclone of 1932. McCollum interested W. Armstrong Price, geologist, to investigate.

In July, 1933, Price photographed craters 51×15 inches in size along the edge of the south ditch of this floodway. The craters were in silt at the northeast corner of the south half of Section 52, at the road on the section line designated as "Mile 2 East."[1] These craters were the sites of huge "boils" of gas during the flood, as reported by Nolan. The "gas" flow made a loud roaring noise.[1]

In spite of the fact that no test of this "gas" had been made, and in spite of the strong probability that it was merely *air* from a deeply cracked clay soil, the large size of the craters made it worth investigation.

A further point of interest was a 3-mile offset in the contact between the Beaumont and the Recent alluvium of the Rio Grande delta just north of the Edcouch and La Villa stations of the Southern Pacific Railroad east of Edinburg, as mapped by A. C. Trowbridge.[2] This mapping seemed to be confirmed in a general way by soil contacts on the Hidalgo soil map. Such an offset could have been produced by uplift along a southeast-northwest axis pointing toward Santa Rosa, or a N. 10° W. axis pointing toward an area between Mercedes and La Feria.

Search along the projection of these hypothetical axes disclosed an area of northwest-southeast-trending sand ridges of 5–10-foot elevations (estimated), previously noted by Nolan as topographically dissimilar to, and higher than, the surrounding clay prairie. The significance of these ridges was not at first fully appreciated, but later work showed that they were probably the bases of ridge-type sand dunes similar to those characteristic of the semi-arid zone over a wide

[1] W. Armstrong Price, "Craters Formed by Air Blowers," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 6 (June, 1934), pp. 813–16, Figs. 1–2.

[2] A. C. Trowbridge, "Tertiary and Quaternary Geology of the Lower Rio Grande Region, Texas," *U. S. Geol. Survey Bull. 837* (1932).

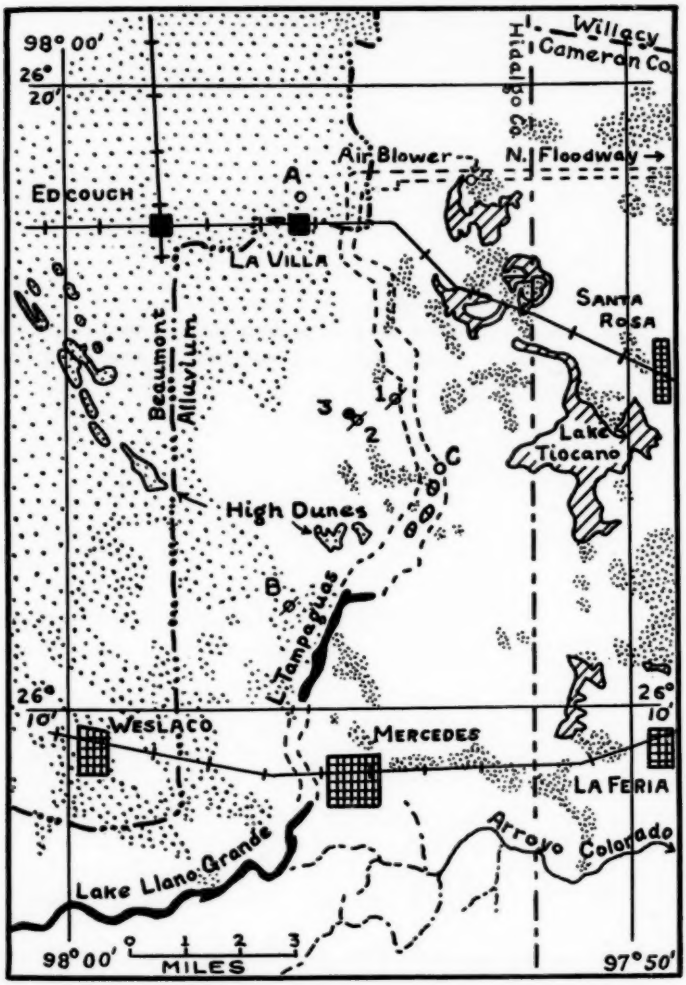

FIG. 1.—Approximate contact between Beaumont formation and Recent alluvium of Rio Grande overflow area, or delta, after Trowbridge, also showing sand and clay soils, sand dunes, shallow lakes (Tiocano clay soil), and discovery oil and gas well of the Mercedes lease block of Union Sulphur Company.

Lake Tiocano is now drained. Fine stipple in east half of map represents low sandy ridges standing on clay or clayey silt; those north and west of Lake Tiocano have elevations of about 5–10 feet. North Floodway of Rio Grande is flanked by artificial levees (indicated by broken lines northward from Lake Llano Grande) and includes basin of Lake Tampaguas. Ancient course of drainage waters in Llano Grande-Tampaguas distributary may have led through small swamps south of well C and thence east to Lake Tiocano.

Localities shown: *A*, Joe Byrnes water well; *B*, old Mercedes Oil Company's well, with oil showing at 3,078 or 3,200 feet; *C*, sour water well in goat pasture; also air-blower craters. Wells of Union Sulphur Company are Nos. 1, 2, and 3 (discovery oil and gas well).

Rio Grande flows at normal stages in its main channel 4 miles south of Llano Grande Lake.

coastal area from points in Mexico south of Rio Grande delta to Falfurrias, Texas, where the writer has described the Falfurrias erg, or sand-dune field, composed of parallel ridges of sand formed by the dominant southeast wind.[3] Concentration of the remnant ridges between La Villa and Santa Rosa was thought possibly to indicate their preservation, over an area of slight recent uplift, from complete destruction by Rio Grande floods. Complete preservation of high sand dunes was noted in the northwest corner of Section 83, just west of the North Floodway and northwest of Tampaguas (or Campacuas) Lake.

A further interesting physiographic feature was the branching and northward termination of Tampaguas Lake, which, with Llano Grande Lake, marks the course of a distributary of Rio Grande. If this distributary formerly flowed northeastward to join Lake Tiocano (now drained), as seems probable, then uplift, probably with faulting, might have interrupted its course between the lakes in Sections 47 and 22. Such a drainage disturbance would be of the same nature as drainage offsets at faults and local uplifts common along the Coast Prairie farther north.

At the same time, a goat-pasture well yielding sour water was pointed out by Nolan in Section 47. The water was strongly salty, while other wells visited had very little salt and only slight mineralization. Inquiry disclosed that several reliable local persons had seen a core with oil of some positive degree of saturation taken from an abandoned well located near the north line of Section 101. The depth of the core was variously reported as 3,078 or 3,200 feet and the total depth not more than a few feet below 3,200 feet. This well is sometimes known as the "Mercedes Oil Company well." Another apparently reliable report of oil was from the Joe Byrnes water well, ½ mile north of the station of La Villa, where a showing of oil and gas was reported by the driller.

While this information was being assembled, a magnetometer survey was made which showed anomalies considered interesting. These anomalies were unclosed "noses" and turned out to lie outside and tangent to the structure as revealed by the reflection survey. This work was done for Price by E. M. Spencer and H. A. Pierce. While it led to the discovery, the magnetic survey did not cover the area of the lease block finally assembled.

Just after the decision to cover the area with a reflection seismo-

[3] W. Armstrong Price, "Rôle of Diastrophism in Topography of Corpus Christi Area, South Texas, "*Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 8 (August, 1933), p. 913 (Fig. 2), p. 933 (Fig. 9), and p. 949.

graph survey had been made by McCollum Exploration Company, the flood in Rio Grande of September, 1933, again caused the craters in the floodway to "boil," as reported by Nolan and his associate Allen Castleberry. Price visited them while the water was falling and collected a can full of the gas taken when the flow had been reduced to trains of small bubbles. This gas cooled the flame of an oiled rag and failed to flash or ignite. It was evidently atmospheric air trapped in fissured soil by the sudden wetting of the surface and by pressure of the river water.

In spite of the failure of the craters to show natural gas, or of the sand at 16 feet below ground surface to yield gas when tapped with a ground augur, the other features of interest described led to the commencement of the seismograph investigation which disclosed a structure of sufficient magnitude to influence the Union Sulphur Company to acquire the large block of leases from McCollum, Nolan, and Price, with their associates, who included Edwin B. Hopkins and E. De Golyer.

In March, 1934, after the prospect had been acquired by the Union Sulphur Company, the McCollum Exploration Company had an east-west profile run through the prospect with a magnetometer, which failed to show an anomaly over the higher points of the reflection structure. This magnetometer work was done by C. W. Platt and W. I. Ingham. A torsion-balance profile run approximately on the same line also failed to show an anomaly, as reliably reported to the writer.

Arthur J. Fecht was the geophysicist in charge of the reflection survey made by the McCollum Exploration Company and R. L. Palmer was assistant geophysicist. J. B. Taylor, petroleum engineer, has been in continuous charge at Mercedes for the Union Sulphur Company since the commencement of their operations.

The original lease block assembled by Tom F. Nolan and W. Armstrong Price comprised approximately 10,000 acres owned by the American Rio Grande Land and Irrigation Company. This block was turned to the McCollum Exploration Company and the latter added about 12,000 acres with the coöperation of Nolan, Castleberry, and Price. The McCollum Exploration Company then turned this 22,000-acre block to the Union Sulphur Company, and the latter increased its holdings to about 35,000 acres before starting the first well.

Locations for the Nos. 1, 2, and 3 wells were made by the McCollum Exploration Company, Nos. 2 and 3 being at their first-choice

location, and No. 1 having been drilled before leasing was completed.

W. ARMSTRONG PRICE

CORPUS CHRISTI, TEXAS
May 25, 1935

TALIHINA CHERT SECTION AT ATOKA, OKLAHOMA

In connection with recent field studies in the Arbuckle-Ouachita region of Oklahoma, the writer has made a stratigraphic section across the upturned exposure of the Talihina chert along Highway 19 about one mile southeast of Atoka. The measurements are based on paced distances and calculated against clinometer measurements of the angle of dip, and are only approximately correct; however, they may be interesting to geologists who do not have any data on the subdivisions at that locality or paleontological evidence and formation correlations in relation to the subdivision of Taff's Talihina chert.[1]

At the point mentioned the beds dip 70° S. 65° E. The section is given downward in order of superposition of strata and numbered downward for references as to correlations.

	Feet
1. Covered by alluvial valley and Trinity débris	
2. Shale; greenish color, weathered to clay	5
3. Chert; dense thin layers, light gray-to-reddish brown	30
4. Shale, thin-bedded, compact, reddish-to-brown with partings of greenish metabentonite. Conodonts	50
5. Chert, dense gray-to-dark, thin-bedded, some greenish with partings of greenish metabentonite and a little thin, papery, dark carbonaceous shale of the type of Chattanooga and Woodford	45
6. Chert, dense, thin-bedded, gray-to-dark	195
7. Shale, papery, drab-to-dark. Contains graptolites	190
8. Chert, dense, thin-bedded, gray-to-dark, some layers calcareous or dolomitic	420
9. Overthrust with fault plane dipping in direction with strata at angle of 17° from horizontal	
10. (Below fault plane) cherty shale, dark, carbonaceous, containing streaks of asphaltite along joints, dips at angle of about 17°, parallel with overlying fault plane	25
11. Covered	
Total	960

With reference to this section, samples from the mid-portion of No. 4 were submitted to Dr. E. B. Branson, of the department of geology at the University of Missouri, in which he found seven specimens of conodonts, two of which belong to the genus *Palmatolepis*, probably species *glabra*. He reports the genus as rather abundant in the Upper Devonian, but states that he has not found it in the basal

[1] J. A. Taff, "Atoka, Indian Territory (Oklahoma)," *U. S. Geol. Survey Atlas Folio 79* (1902).

Mississippian. He considers Woodford shale as Devonian. Therefore, No. 4 is herein correlated as Woodford shale. Since No. 5 contains some layers of shale typical of Woodford shale, it is correlated as Woodford. No. 6, being in the position of the Hunton group, is so correlated. No. 7, containing numerous specimens of graptolites, is considered a typical section of the Sylvan shale. In order to observe its outcrop, one must follow its valley about a quarter of a mile northward along the strike across a small divide to where it is well exposed in a ravine between the hogbacks formed by No. 6 and No. 8. No. 8 is correlated with the Viola limestone. The writer makes no effort to correlate No. 10 below the low-angle overthrust. He is of the opinion that the fault is a minor displacement and is confined to the immediate vicinity. Bed No. 10 is not typical of the shales exposed near Stringtown which Taff called Stringtown shale. The shale near Stringtown is much like No. 7, if not actually the same bed, its stratigraphic position having been confused by overturning along the major fault zone.

It is the writer's opinion that there is no great difference between the so-called Arbuckle and Ouachita sequences of strata other than a natural transition in deposition from one province to the other. The gradation from limestone to chert and the color changes are the outstanding changes in approaching the Ouachita geosyncline from the Arbuckle area. It is believed that this transition occurred in a distance of less than 5 miles; it is shown in traversing the outcrop of the Talihina group from north to south in the Stringtown area, this line being a component of the direct original transition toward the southeast. It is believed that the distance of thrusting toward the northwest along the major fault zone is limited and that the strata lie reasonably near their original position of deposition.

In connection with correlations with the Ouachita sequence as shown in the Hot Springs folio,[2] the writer calls attention to the probabilities that No. 3 is part of the Arkansas novaculite and No. 4 is Missouri Mountain shale. The Blaylock sandstone may be a sandy phase of the Hunton. No. 7 is in the position of the Polk Creek shale with which it is probably correlative, and No. 8 (Viola) is probably the Big Fork chert.

JAMES H. GARDNER

TULSA, OKLAHOMA
June 6, 1935

Mr. Gardner's last paragraph is subject to question. Since his bed

[2] A. H. Purdue and H. D. Miser, "Hot Springs, Arkansas," *U. S. Geol. Survey Atlas Folio 215* (1923).

No. 4 is correlated with the Woodford on good evidence, it can not be the Missouri Mountain shale. The Missouri Mountain shale underlies the Arkansas novaculite, and the lower part of the Arkansas novaculite is, on fairly good faunal evidence, Middle Devonian. The Blaylock sandstone contains Silurian graptolites, and the Missouri Mountain shale is therefore Upper Silurian or Lower Devonian in age. I believe that the correlations of the Polk Creek shale with the Sylvan shale and of the Big Fork chert with the Viola limestone are nearly correct, although Ulrich has published a long discussion in which he contends that the Sylvan and Polk Creek are not correlative.[3]

IRA H. CRAM

TULSA, OKLAHOMA
June 17, 1935

PERMEABILITY OF UNCONSOLIDATED ROCKS

In 1932 the writer studied the effect upon the porosity of uncemented sands of grain-size distribution, angularity, and compaction. The report of these tests[1] showed that porosity is an exponential function of compaction pressure. The same paper described a portable air porosimeter and permeameter.

An instrument has now been designed which embodies the same principles and the portable features of the preliminary model, and which can be used for measuring the permeability of cemented and uncemented sediments of both low and high permeabilities.

The apparatus may be described with reference to Figures 1 and 2.

In Figure 1, *a*, is the core barrel, used with No. 12 (1.7 mm. diameter) chilled steel shot. The rock is soaked in water to prevent infiltration of cuttings and a cylinder about one inch long is milled out. The cylinder is mounted in the chuck of a machine-lathe and one end is squared off with a tool armed with a tungsten-carbide cutting point. The core is then set in a brass sleeve and woods metal of melting point 130°C. is poured in, thus cementing the core in the sleeve. The sleeve is then mounted in the lathe and the other side dressed off so that the core and sleeve are about 1.5 centimeters in length. The cores used are 4.5 centimeters in diameter, but smaller ones can be used in the same apparatus by using an adaptor. The mounted core is shown in *b*. The core and sleeve are then dried in an oven and

[3] E. O. Ulrich, *Bull. Geol. Soc. America*, Vol. 37 (1926), pp. 279–348.

[1] Frederick G. Tickell, O. E. Mechem, and R. C. McCurdy, "Some Studies on the Porosity and Permeability of Rocks." *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 103 (1933), pp. 250–60.

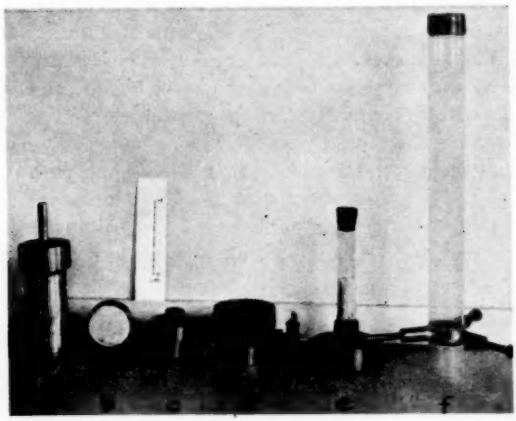

FIG. 1.—Core-cutter, mounted core, and disassembled permeameter.

FIG. 2.—Permeameter, assembled and ready for test.

set in the part *d*, making an air-tight joint by means of plasticene. The part *e* makes a ground-joint fit with lubriseal on the part *d*, and part *d* makes another ground-joint fit on *f*. The glass tube in *e* contains calcium chloride for drying the intake air. The glass tube in *f* has graduations 5 centimeters apart, and the lugs at the bottom telescope, so that the tube may be lowered, for filling, inside the large glass vessel shown in Figure 2.

For rocks of high permeability, or for unconsolidated samples, a smaller core and sleeve are used with an adaptor, as shown in *c*.

The assembled apparatus is shown in Figure 2. After testing for leaks, the valve in *d* is opened and tube *f* lowered to the bottom of the large vessel, *g*, thus filling *f* with water. The valve is then closed and tube *f* raised so that it stands on top of the large vessel with the lower end dipping into the water therein. The cork in *e* is then removed, air passing through the specimen and displacing the water in *f*. The time is noted for the water meniscus to pass from one graduation to another.

The test for viscous flow and the calculation of permeability can be made in a manner similar to that described by Wykoff[2] *et al.* If, however, certain conditions are maintained and certain assumptions are made, the instrument may be calibrated so that permeability:

$$K = \frac{\text{a constant}}{\text{efflux time}}$$

The maintained or assumed conditions are:

1. Viscosity of air is constant for the working conditions.
2. Variations in atmospheric pressure are negligible.
3. Expansion of air is isothermal.
4. Boyle's law is satisfied.
5. Dimensions of the sample are the same in each case.
6. The air flow through the sample is viscous. This can be checked by knowing the critical velocity of the water meniscus between two given points. This critical velocity may be determined for the instrument by choosing a sample permeable enough to give turbulent flow at the maximum efflux rate; this is, while the water meniscus is passing between the top and the second graduations of the tube. Efflux times are then taken for each graduation interval from the top to the bottom, and from these data, together with the dimensions of the sample and the instrument, the efflux rate per unit of core area ($\overline{Q}/A$)

[2] R. D. Wyckoff, H. G. Botset, M. Muskat, and D. W. Reed, "Measurement of Permeability of Porous Media," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 2 (February, 1934), p. 177.

is plotted against the pressure gradient per unit of sample length $(P_1-\frac{P_2}{L})$. This gives a straight line through the origin for the viscous flow region, and a curved line for the turbulent flow region. The critical velocity, therefore, is at the point of tangency of this curve. Wykoff[3] describes this method fully for the general case.

It is evident that, in the use of this instrument, the head is variable. The computations must take this into account. The necessary equations are:

$$\bar{Q}/A=\frac{h_1-h_2}{t}(D^2/d^2)\left[1-\left(\frac{h_1+h_2}{4P_1}\right)\right]$$

$$\frac{P_1-P_2}{L}=\frac{h_1+h_2}{2L}$$

$$K=\mu\left[\frac{\bar{Q}}{A}\right]\left[\frac{L}{P_1-P_2}\right]$$

where

K = permeability (darcys)
μ = absolute viscosity of air (centipoise)
$\bar{Q}$ = rate of efflux referred to mean pressure $\bar{P}$ (cm.^{3} per sec.)
$\bar{P}$ = arithmetic mean of pressures on either side of core
h_1 = initial height of column of water (cm. of water)
h_2 = final height of column of water (cm. of water)
P_1 = barometric pressure (cm. of water)
P_2 = inner pressure (cm. of water) $P_2=P_1-\frac{h_1+h_2}{2}$
A = area of core (cm.^{2})
L = length of core (cm.)
D = diameter of water column (cm.)
d = diameter of core (cm.)
t = efflux time (sec.)

Water heads are measured from the meniscus in the tube to the meniscus in the jar, g, and deduction must be made for the rise of water in the jar.

Effect of grain size and compaction on permeability.—Use of this instrument has been made to study the effect of grain-size distribution and compaction on the permeability of unconsolidated sediments.

Sand of the following mechanical analysis was used as the basic material.

[3] *Op. cit.*, p. 177.

Mesh (Tyler Standard)	*Cumulative Percentage Passed by Screen*
20	100.0
28	99.1
35	95.0
48	89.1
65	81.1
100	68.8
150	51.4
200	26.8

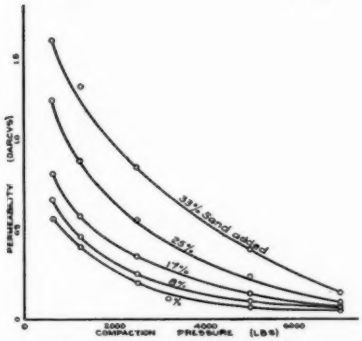

FIG. 3.—Permeability as function of total compaction pressure for various percentages of added sand.

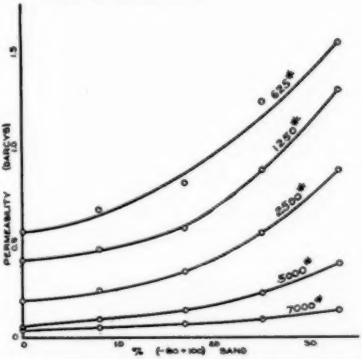

FIG. 4.—Permeability as function of percentage of −80+100 sand added to basic mixture, for various compaction pressures.

To this was added various percentages of −80, +100 mesh quartz sand (Ottawa silica sand) and the mixtures were compressed into brass sleeves (Fig. 1, *c*) having inside diameter of 2.105 centimeters. Total pressures varying from 625 pounds to 7,000 pounds were used.

In Figure 3 is plotted permeability of the various mixtures against total compaction pressure. These curves are straightened by plotting on semi-log paper, but not on double log paper, hence the relationship is best expressed as an exponential one, as was also found for porosity versus compaction.

In Figure 4 are plotted the same data with permeability against percent of sand added to the basic sand. These curves indicate that adding sand to a fine-grained aggregate has less effect on the permeability when the mixture is highly compressed than when compressed to a lesser degree. In other words, the deduction might be made that increasing sandiness of a deeply buried stratum has less effect on the permeability than in the case of a shallow stratum.

FREDERICK G. TICKELL

STANFORD UNIVERSITY, CALIFORNIA
June 13, 1935

DISCOVERY OF OIL AT BIG MEDICINE BOW ANTICLINE, CARBON COUNTY, WYOMING

The most important oil discovery in Wyoming since Salt Creek is the new well on Big Medicine Bow anticline in Carbon County, owned jointly by The Ohio Oil Company and The California Company. The new well, known as Kyle No. 1 and located in the NE., SE., NE. of Sec. 26, T. 21 N., R. 79 W., was completed to the depth of 5,391 feet on May 10, 1935, and in a 5-hour test, produced 795 barrels of oil of 63° A.P.I. gravity from the second bench of the Sundance (Jurassic) sand at 5,299–5,391 feet. It had previously developed 36 million cubic feet of gasoline-saturated gas in the upper part of the Sundance sand at 5,151–5,206 feet. The well was commenced in the Mesaverde formation (late Upper Cretaceous) at an elevation of 7,271 feet and had the top of the Dakota group (early Upper Cretaceous) at 4,830 feet.

The Big Medicine Bow anticline gives every promise of developing into an oil field of major importance. It is a long anticline in T. 20 and 21 N., R. 79 W., with more than 2,700 feet of structural closure, and embraces more than 10 sections of possibly productive area above lowest closing contour. The anticline widens slightly near its crest and narrows toward the south. Its steepest flanks are on the east and north where the dip of the beds ranges from 20° to 75°. On the south the dips are more moderate and average 7° or 8°. A sharp syncline is present on the northeast, and more gentle synclines on the south and southwest. The fold is in an area of rugged relief caused by the cliff-forming sandstones of the Mesaverde formation. The "Teapot" sand-

stone member at the top of the Mesaverde formation forms an almost continuous escarpment around the flanks of the anticline. This sand-

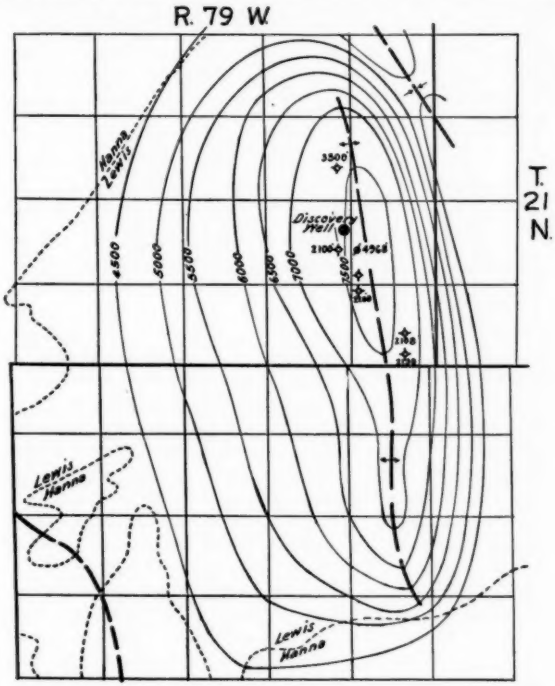

FIG. 1.—Map showing structure of Big Medicine Bow anticline contoured on sandstone in Meseverde formation (Cretaceous) approximately 1,300 feet above base of formation. Hanna formation is Tertiary. Lewis formation is late Upper Cretaceous. From *Résumé of Rocky Mountain Oil and Gas Operations for 1934* (February 9, 1935), by Petroleum Information, Inc., Continental Oil Building, Denver, Colorado.

stone is immediately below the Lewis shale formation which crops out in the lower lands around the fold.

C. E. SHOENFELT

DENVER, COLORADO
June 6, 1935

SAFETY OF WATER-FLOODING PRESSURES AT BRADFORD, PENNSYLVANIA

CORRECTION

In the article, "Safety of Water-Flooding Pressures at Bradford, Pennsylvania," by Frederick G. Clapp, in the June *Bulletin*, on page 812, Plate V, the labels *A* and *B* of the two photographs should be transposed. The upper photograph shows the crater of Rachal well No. 7. The lower photograph shows the crater of the White Point Development Company's well No. 2.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 19, NO. 8 (AUGUST, 1935), PP. 1240-1245

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library and available to members and associates. A list of technical periodicals available for loan to members and associates was published in the *Bulletin*, Vol. 18, No. 9 (September, 1934), pp. 1215-17.

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* *Introduction to Geology*. By E. B. BRANSON and W. A. TARR. McGraw-Hill Book Company, Inc., New York (1935). 470 pp., 456 figs. 6×9 inches. Cloth. Price, $3.75.

This book will be interesting to petroleum geologists because the authors are members of our Association, and also because the presentation is refreshingly different from any recent elementary text. It aims to cover a course offered for its general cultural value to students who for the most part will not study the subject further. It will help the specialist in petroleum to be reminded of the fascination of geology and to note progress in teaching it, quite aside from the application which he makes of it.

The order of treatment of physical geology topics is unusual. While this may lead to some lack of clarity in the student's mind as to the analysis of the subject into logical subdivisions, an important result is to hold his interest in an unfolding narrative of related matters. The somewhat dry and analytical presentation of each class of rocks, each agency of gradation, and of types of diastrophism, so common in our textbooks, is abandoned.

The treatment begins with up-to-date views about the constitution of matter, based partly on X-ray patterns, and passes next to volcanism. Here the composition of magmas seems over-emphasized, but it leads to a discussion of igneous rocks and of ore deposits. The following presentation of weathering processes also seems to require a considerable interest in chemistry if the student is to understand the chemical weathering of igneous rocks of several different types. The next subjects treated are the work of running water, ground water, and the oceans. Many familiar and hackneyed details are omitted without serious loss, and certain aspects of operations not usually emphasized are presented with good illustrations and fresh flavor. Then for the first time comes a classification of sedimentary rocks, including some desirable explanations of the importance of colloidal silica, and of the mingling of chemical and organic limestone sediments. The treatment of metamorphic rocks is excellent, but differs from many texts in excluding quartzite and anthracite. The treatment of structural geology is adequate and well illustrated for beginning students, although a number of usual details are omitted. On the whole the presentation of physical geology lives up to the aim of the authors, as announced in the introduction, and is interesting and of cultural value rather than an adequate book for geology majors. It seems to the reviewer, however, to be undesirably heavy on the chemical side.

The subject of historical geology, likewise, is an interesting presentation, without too heavy a treatment of the earth's origin or too dry a repetition of details relating to each separate period. The lithologic and fossil characteristics of the rocks are described with desirable brevity, and the emphasis is placed on a generalized view of the historical events of repeated invasions and

retreats of the sea, the accompanying crustal movements, and the resultant effects on living creatures. The evolution of life and its characteristics from time to time are presented very effectively, doubtless due as much to what is omitted as to the part included. Petroleum geology is explained following discussion of the early Paleozoic formations. This and the subsequent good discussions of economic products at appropriate intervals serve to prevent dullness for the reader. The student's interest is sustained and he will leave this book with no feeling of anticlimax due to the historical geology.

FRANK W. DEWOLF

URBANA, ILLINOIS
June 24, 1935

**Engineering Surveys.* By HARRY RUBEY. XV+321+109 pp., 254 figs. Cloth. 5×7.75 inches. The Macmillan Company, New York (1934). Price, $3.00.

This book is a comprehensive treatment of elementary surveying, in which much space is devoted to methods and procedures employed in topographic and land surveys.

The first seven chapters give descriptions of the various surveying instruments and instructions as to their care, adjustments, and uses. The remainder of the text is devoted to the different kinds of surveys, field procedures, and office methods, and to the organization and cost of surveys. Following the text are tables of logarithms of both numbers and trigonometric functions, natural trigonometric functions, stadia coefficients, convergence of meridians, differences in longitude and latitude, and formulas.

The chapters on meridian determination, stadia, topography, and triangulation are unusually complete for an elementary book. Chapter XII, "Land Surveys," is exceptionally complete. Not only is the system of public land division employed by the United States General Land Office given in detail, but also are quoted the rules governing the limits of error and closure, restoration of lost corners, resurveys and the like, which are employed by this office.

The book is well written, and is of exceptional clearness because of the use of simple language, the many examples, and the large number of figures. The emphasis given to the sources of blunders and errors, together with statements of the accuracy of various types of surveys, is a commendable feature.

The comprehensive treatment of the subject and the space devoted to topographic and land surveys make this book a desirable reference on surveying for the geologist.

A. N. MURRAY

UNIVERSITY OF TULSA
TULSA, OKLAHOMA
June, 1935

RECENT PUBLICATIONS

ARGENTINA

* "Relaciones estratigráficas y faunistícas entre los estratos cretáceos y terciarios en la región de lago Argentino y en la del golfo de San Jorge-Patagonia" (Stratigraphic and Faunal Relations Between Cretaceous and Tertiary Beds in the Region Between Lake Argentina and the Gulf of St.

George—Patagonia), by Egidio Feruglio. *Y.P.F. Bol. de Inform. Petrol.* (Paseo Colon 922, Buenos Aires), Vol. 12, No. 128 (April, 1935), pp. 69–93. First of a series.

AUSTRALIA

* "Geological Factors in Oil Prospecting with Reference to Australia," by D. Dale Condit. Reprinted from *Australian Geographer* (Sydney), Vol. 2, No. 6 (May, 1935). 15 pp., 1 fig.

BRAZIL

* "Resumo dos resultados dos estudos geofisicos no estado do Rio Grande do Sul" (Résumé of Results of Geophysical Studies in the State of Rio Grande do Sul), by Mark C. Malamphy. *Inst. Geol. e Min. do Brasil, Relatorio Annal do Director, Ano 1932* (Rio de Janeiro, 1934), pp. 25–28. Paper 7.125×10.625 inches.

* "Reconhecimento geológico no estado do Rio Grande do Sul" (Geological Reconnaissance of the State of Rio Grande do Sul), by Paulino Franco do Carvalho. *Serviço Geol. e Min. Bol. 66* (Rio de Janeiro, 1934). 72 pp., 3 figs., 28 photos, 2 pls. Paper. 7.125×10.625 inches.

* "Reconhecimentos geológicos no vale do Tapajoz" (Geological Reconnaissances in the Valley of the Tapajoz), by Pedro de Moura. *Ibid., Bol. 67.* 53 pp., 1 fig., 34 photos, 1 pl. 7.125×10.625 inches.

* Rochas gondwanicas e geologia do petroleo do Brasil meridional (Gondwana Rocks and Petroleum Geology of Southern Brazil), by Victor Oppenheim. *Republica dos Estados Unidos do Brasil Serviço do Fomento da Produção Mineral Bol. 5* (1934). 129 pp., 5 charts, 53 photos, 29 line drawings (sketches, folded sections and maps). This bulletin is the text to accompany the author's Map of the Geology of Southern Brazil, with Special Reference to the Gondwana Formations (2 sheets in colors, each about 35×18 inches; scale, 1:2,750,000). Paper. Size, 6.25×9 inches. Requests should be addressed to the director, Serviço do Fomento da Produção Mineral, Avenida Pasteur 404, Rio de Janeiro, Brasil.

GENERAL

"Petroleum Development and Technology, 1935," by the Petroleum Division. *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 114 (1935). 554 pp., illus. Chapter I, "Production Engineering and Engineering Research," contains 21 articles; Chapter II, "Use of Metals in the Petroleum Industry," 8 articles; Chapter III, "Stabilization," 3 articles; Chapter IV, "Petroleum Economics," 5 articles; Chapter V, "Production," 26 reports on 19 states and 20 reports on 22 countries outside the United States of America; and Chapter VI, "Refining," 1 article.

* *Oil and Petroleum Year Book, 1935*, compiled by Walter E. Skinner. VIII+352+advertising pages. 26th ed. Size 5.365×8.25 inches. Cloth. Contains in concise form particulars about 678 companies engaged in every branch of the oil industry throughout the world. Lists company officials. Statistics. Production. Glossary of technical terms. Walter E. Skinner, 15, Dowgate Hill, Cannon Street, London, E. C. 4. Price, 7s, 6 d, net, postpaid.

* *Report of the National Research Council for the Year July 1, 1933–June 30, 1934.* Reprinted at the U. S. Govt. Printing Office, Washington, D. C. (1935) from the Annual Report of the National Academy of Sciences for the Year July 1, 1933–June 30, 1934. 92 pp. Size 5.75×9.625 inches. Paper.

* "Fossil Crustacea of the Atlantic and Gulf Coastal Plain," by Mary J. Rathbun. *Geol. Soc. America Spec. Paper 2* (1935). 160 pp., 2 figs., 26 pls.

* "Die Entstehung vulkanartiger Bauformen in Erdölgebieten" (The Origin of Volcano-like Structural Forms in Oil Fields), by Karl Krejci. *Borhtechniker-Zeitung* (Wein), Vol. 53, No. 6 (June 15, 1935), pp. 149–51; 3 figs.

Earthquakes and Mountains, by Harold Jeffreys. Methuen and Company, London (1935). Price 7s.6d.

GEOPHYSICS

* "Considérations sur la Géophysique" (Notes on Geophysics), by C. Schlumberger. *Rev. de Petrolifère* (Paris), No. 633 (June 1, 1935), pp. 680 and 704.

* "The Effect of Topography and Isostatic Compensation Upon the Intensity of Gravity." *U.S. Coast and Geodetic Survey*. Obtainable from Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $0.35.

GERMANY

* "Das Vorkommen von Erdöl und Erdgas, von Jod- und Schwefelwasser in südlichen Bayern" (Occurrence of Petroleum and Natural Gas, from Iodine and Sulphur Water in Southern Bayern), by K. A. Weithofer. *Petrol. Zeit.* (Berlin), Vol. 31, No. 22 (June 1, 1935), pp. 1–8. First of two articles.

* "Die Tektonik des niederrheinschen Salzgebirges" (The Tectonics of the Lower Rhine Salt Ranges), by E. Zimmermann. *Kali, Verwandte Salze, und Erdöl* (Wilhelm Knapp, Halle, Saale), Vol. 29, No. 11 (June 1, 1935), pp. 113–15, Fig. 1; No. 12 (June 15, 1935), pp. 123–26, Figs. 2–5.

ITALY

* *Petroleum* (Verlag für Fachliteratur, G. m. b. H., Wien, Austria), Vol. 31, No. 24 (June 12, 1935). Special number on the development and present status of the oil industry in Italy. Contains among others the following articles, in German.

"Italian Petroleum Industry," anon. Pp. 2–8; 12 figs.

"The Development of A.G.I.P. (Azienda Generale Italiana Petroli," anon. Pp. 9–20, 21 figs.

"Contribution of Geophysics to the Petroleum Geology Investigations of A.G.I.P.," by A. Bellingi. Pp. 21–23.

"Petroleum-Bearing Beds of Mediterranean Type," by Stanislaw Zuber. Pp. 24–27; 5 figs. (geologic sections.)

"Electrical Coring," anon. 4 figs.

JUGOSLAVIA

* "Chemical Investigation of Iodine Mineral Waters in Jugoslavia," by Stanko S. Miholíc. Reprint from *Glasnika Hemiskog Drustva Kraljevine Jugoslavije* (Beograd), Vol. 5, Nos. 3–4 (1934), pp. 155–77; 1 sketch map and 7 tables. In Polish. English abstract, pp. 176–77. "In spite of the abundance of iodine waters and occurrence of natural gas in many places, the prospects for the development of an oil industry in Jugoslavia are not encouraging owing to the fact that petroleum-bearing strata consist mainly of very fine material (silt and clay), which does not yield its petroleum to drilling operations."

MICHIGAN

* "Geology and Economic Significance of Central Michigan Fields," by

Basil B. Zavoico. *World Petroleum* (New York, May, 1935), pp. 309–24; 14 illus.

MONTANA

* "Geology of Big Horn County and the Crow Indian Reservation, Montana, with Special Reference to the Water, Coal, Oil, and Gas Resources," by W. T. Thorn, Jr., G. M. Hall, C. H. Wegemann, and G. F. Moulton. *U. S. Geol. Survey Bull. 856* (1935). vii, 200 pp., 15 pls. (including 6 maps), 13 figs. Available from Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $0.60.

NEW YORK

* "Structure and Gas Possibilities of the Watkins Quadrangle, New York," by W. H. Bradley. *U. S. Dept. Interior Press* Notice 101944 (June 14, 1935). 14 mimeogr. pp., 4 figs.

OKLAHOMA

* *Gorman's Petroleum Directory of Oklahoma, 1935.* The latest edition whose purpose is "to list all the companies and individuals in the State of Oklahoma, who are directly or indirectly connected with the production of petroleum." Besides companies, it includes drilling contractors, geologists, and abstracters. 116 pp. Approx. size, 4.5×7.5 inches. Paper. B. R. Gorman, Box 395, Tulsa, Oklahoma. Price, $1.00.

POLAND

* "Analizy krzywych produkcji piaskowca Boryslavskiego" (Analysis of Production Curves in the Boryslaw Sandstone), by O. V. Wyszyński. *Carpathian Geol. Survey Bull. 26* (1935). 32 pp., 20 figs. 27 pp. in Polish, 5 pp. in English (abstract).

ROUMANIA

* "Zagadienie pochodzenia ropy w Karpatach Rumúnskich" (Present State of Geological Knowledge on the Problem of the Genesis of Petroleum in the Region of the Roumanian Carpathians), by I. P. Voiteşti. *Carpathian Geol. Survey* (Boryslaw, Poland). *Karpaty i Przedgórze.* III (1935), pp. 91–116.

RUSSIA

* "New Data on the Oil-Bearing Capacity of Eastern Turkmenia," by N. A. Orlov and V. P. Miroshnichenko. *Problems of Soviet Geology* (Moscow), Vol. 5, No. 2 (1935), pp. 199–202; 2 figs. In Russian.

WYOMING

* *Areal and Structural Geology of the Garland Anticline, Big Horn and Park Counties, Wyoming*, by C. E. Dobbin, J. C. Miller, and K. C. Walter. *U. S. Geol. Survey* (1935). Map of 75 square miles adjacent to town of Byron, on scale of 1:48,000. A few copies for free distribution at U. S. Geol. Survey, Washington, D. C.; 523 Customhouse, Denver, Colorado; 305 Federal Building, Casper, Wyoming; 305 Federal Building, Billings, Montana.

PUBLICATIONS OF DIVISION OF PALEONTOLOGY AND MINERALOGY

* *Journal of Paleontology*, Vol. 9, No. 5 (July, 1935).

"*Atrypae* Described by Clement L. Webster and Related Forms (Devonian of Iowa)," by Carroll Lane Fenton and Mildred Adams Fenton.

"A Plesiosaur from the Upper Cretaceous of Manitoba," by Loris S. Russell.

"A New Antilocaprid from the Upper Pliocene of Idaho," by C. Lewis Gazin.

"Larval Stages of Trilobites from the Middle Cambrian of Alabama," by Cecil G. Lalicker.

"Protaspides of Trilobites," by Percy E. Raymond.

"A Revision of the Phacopid Trilobites," by David M. Delo.

"New Phacopinae from the Devonian of Oklahoma and Iowa," by David M. Delo.

"The Genotype of *Dalmanites*," by David M. Delo.

"A Conularia from the Permian of Arizona," by Edwin D. McKee.

"A Pliocene Ophiuran from Trinidad," by Charles T. Berry.

"Graptolites from the Silurian of Oklahoma," by Charles E. Decker.

"Silurian Phyllocarid Crustaceans from Oklahoma," by Rudolf Ruedemann.

PUBLICATIONS OF DIVISION OF GEOPHYSICS

* *Journal of Geophysics*, Vol. 1, No. 1 (August, 1935).

"Notes on the Early History of Applied Geophysics in the Petroleum Industry," by E. DeGolyer.

"On the Strategy and Tactics of Exploration of Petroleum," by E. E. Rosaire.

"Explosives and Electric Blasting Caps for Geophysical Prospecting," by G. H. Loving and G. H. Smith.

" Note on the Theory of Seismic Prospecting," by C. H. Dix.

"Discovery of Small Producing Structures by Reflection Seismograph," by G. H. Westby.

"Portable Dynamite Storage Magazines," by J. W. Flude.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 19, NO. 8 (AUGUST, 1935), PP. 1246-1250

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to J. P. D. Hull, business manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

Ralph H. Cummins, Fort Worth, Tex.
Claude F. Dally, H. Smith Clark, H. B. Fuqua
Alfred Grossmann, Cumarebo, Venezuela, S. A.
C. Wiedenmayer, G. Moses Knebel, John W. Brice
Charles Albert McCann, Midland, Tex.
H. B. Fuqua, B. E. Thompson, J. B. Lovejoy
Rolland W. McCanne, McFadden, Wyo.
C. J. Hares, W. T. Nightingale, H. F. Davies
Frank Fisher Reynolds, Houston, Tex.
Paul Weaver, John S. Ivy, H. C. Spoor, Jr.
George Elijah Tash, Maracaibo, Venezuela, S. A.
Alfred P. Frey, H. Hemmings, Joe Netick

FOR ASSOCIATE MEMBERSHIP

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James A. Waters, Francis E. Heath, P. W. McFarland
Robert Ira Dickey, Midland, Tex.
Georges Vorbe, F. H. Schouten, Jack C. Pollard
Everett Eaves, Oklahoma City, Okla.
T. M. Ragsdale, John E. Van Dall, Oscar Hatcher
Robert Gilbert Hamilton, Houston, Tex.
A. C. Trowbridge, A. C. Tester, Anthony Folger
John Moore Hills, Midland, Tex.
W. D. Anderson, A. R. Denison, J. F. Hosterman
Thomas F. Johnston, Houston, Tex.
John C. Miller, Louis A. Scholl, Jr., George D. Mitchell, Jr.
Wilton W. La Rue, Houston, Tex.
Louis A. Scholl, Jr., Elton Rhine, Paul Weaver
William F. Snebold, Fort Worth, Tex.
H. B. Fuqua, Claude F. Dally, D. P. Dean

FOR TRANSFER TO ACTIVE MEMBERSHIP

August F. Beck, Tulsa, Okla.
Edmond O. Markham, L. Murray Neumann, Stuart Sherar

MID-YEAR MEETING, MEXICO CITY, OCTOBER 16–17, 1935

More and more inquiries are coming in about the mid-year meeting of the Association. The San Antonio committee is purposely not acting hastily in its deliberations. It desires to be helpful in advising about road conditions for automobile travel, rates and schedules for rail and air travel, and other pertinent matters. However, A.A.P.G. members and most other geologists are peculiarly capable in arranging for their individual comfort and convenience according to their own circumstances. Therefore, local transportation agents will as usual be convenient sources of information. At present, the plans and possibilities of the meeting are set forth in the following informal paragraphs, which, however, bear the official sanction of Joseph M. Dawson, president of the San Antonio Section.

It has been the plan of the local committee to make the trip by auto from San Antonio to Laredo, and over the new Mexican paved highway through Monterrey to Mexico City, as set forth in the announcement mailed to all members last June. Adverse reports by travellers returning from recent international conventions in Mexico City should not discourage those who plan to drive in October, a dry month. The river crossings are made by ferry or temporary bridges except at flood stage. If there should occur unlooked-for rains of great volume in October that make the rivers impassable it will be necessary to take the train at Valles, 450 miles south of Laredo, into Mexico City. This takes about 20 hours from Valles. The road is always good, it being paved, from San Antonio to Valles. The rains are so definitely seasonal in this part of Mexico that there is only a remote chance of serious rains at that time.

For those who desire to travel by plane or train, the following tentative rates and schedules may be checked with local agents. In general, the current seasonal roundtrip rates are as low as those that are otherwise granted as convention rates. Transportation officials, like geologists, are careful in making guarded statements; therefore, these figures are subject to change without notice.

The plane schedule from San Antonio to Mexico City, one plane each way daily, is: leave San Antonio at 6:15 A.M., arrive at Brownsville at 8 A.M.; leave Brownsville, 9 A.M., and arrive Mexico City, 1:45 P.M. The fare is $54.00 one way, or a 10 per cent reduction for the roundtrip, which is a total of $97.20. A plane leaves Oklahoma City at 3 A.M., arrives at San Antonio at 6:05 A.M., and departs at 6:15 A.M., as per the above schedule. The fare from Oklahoma City to Brownsville is $40.50 each way, less 10 per cent for the roundtrip, or $72.90. Roundtrips to Brownsville from Tulsa, $81.00; from Dallas or Forth Worth, $50.40; from Houston, $32.40. The roundtrip from Brownsville to Mexico City is $73.80.

As to the train fare, the roundtrip from San Antonio to Mexico City is $43.50, and a lower berth, for one person or two, roundtrip for $23.65. In this is included a side trip from Mexico City to Guadalahara for one day. The schedule is to leave San Antonio at 9 P.M., and arrive in Mexico City at 8:45 A.M., the second day, a 36-hour trip. The trip can also be taken by leaving San Antonio at 8 A.M., and arriving in Mexico City at 8 P.M., the next day. This latter trip, however, is not suggested, as it does not have complete diner service. The train that leaves San Antonio at 9 P.M. is air-conditioned,

with excellent food service and observation car. This is by far the best schedule. This same train can be boarded at Laredo at 3 A.M., with the round-trip fare approximately $32.00. It can also be boarded at Monterrey at 8:50 A.M., with the roundtrip fare of approximately $27.00. There is only a limited amount of Pullman space available out of Monterrey. If 15 tickets or more are sold out of San Antonio a special car will be provided.

The roundtrip rail fare to Mexico City from Tulsa (reduced rate of fare and one-third) is $66.50, plus $38.40 for Pullman lower, roundtrip. The round-trip fare from Los Angeles is $79.05, plus $31.05 for Pullman.

As to the technical session it has been decided to divide the meeting into two morning sessions, Wednesday, October 16, and Thursday, October 17. This will give the opportunity for sightseeing trips on two afternoons for the geologists who will only be able to stay two days. A dance is planned for Wednesday night.

Busses will be provided, at the individual's expense, on the two afternoons, for trips to the floating gardens of Xochomilco, the Desert of the Lions, Chapultepec castle, Indian graves under basaltic lava flows, and to the National museum.

The golf course will be available for those who care to play. The Jai-Alai games will be in progress and can be seen any night.

The technical program, in part, arranged so far is: (1) "The Main Physiographic Provinces of Mexico," by E. Ordoñez; (2) "The General Geology of Mexico," by James L. Tatum; (3) "Geology of Northeastern Mexico, Correlated with Southwest Texas," by W. G. Kane; (4) "The History of Mexico," tentative; (5) "The Tampico Oil Fields," possibly by John Muir; (6) "A History of Mining in Mexico," tentative; (7) "Salt Domes of Texas and Mexico, with Particular Reference to the Isthmus of Tehuantepec," probably by Paul Weaver; (8) a paper by a member of the Geological Institute of Mexico. All papers will be in English.

Arrangements have been made with representatives of the Real del Monte silver mines at Pachuca for an inspection trip through their mines at Pachuca, which produce 10 per cent of the world's silver, and have been in operation, by Indians, Spaniards, and Mexicans, for 300 years. The mines will be visited either on the way down or on the way back, as it is only 3 or 4 miles off of the highway.

Tom Callahan has agreed to act as guide through the Tampico oil fields and arrangements will be made for this trip also.

The convention members will be welcomed by the mayor of Mexico City.

It is suggested that all cars that drive down that are now insured can get full coverage in Mexico by application to the company now having the car insured, at no cost to the owner. A rider to the policy is supplied by each company. Otherwise insurance can be purchased at a low cost at Laredo, although it is not required or necessary.

It is hoped that a pictographic map can be furnished for publication in the September *Bulletin*.

All committees will be announced in the September *Bulletin*.

The San Antonio committee plans to furnish at the meeting a rather complete bibliography for those interested in the further study of Mexico. A partial list appeared in the July *Bulletin*. The following additional titles have

been suggested for those who may desire to obtain a reading background for the full appreciation of the trip:

Guide to Mexico, by T. Philip Terry (Houghton Mifflin, 1930). Detailed and generally accurate.

Tepoztlan, A Mexican Village, by Robert Redfield (University of Chicago, 1930). Detailed picture of daily life in the interior.

Viva Mexico, by Charles Macomb Flandrau (Appleton, 1908). Entertaining account of Mexico of earlier years.

The Plumed Serpent, by D. H. Lawrence. Artistic and romantic.

Let's Go to Mexico (*Time Out for Adventure*), by Leonidas W. Ramsey. Profusely illustrated by J. Anthony Kelly. 315 pp. Doubleday, Doran and Company, Inc., Garden City, New York (1935). Not a guidebook, though full of all sorts of valuable and picturesque information. The happy record of two Americans, an advertising man and an artist, on a vacation in search of adventure. Price, $2.75.

HUAUTLECA GIRL, STATE OF OAXACA

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 19, NO. 8 (AUGUST, 1935), PP. 1251-1252

AT HOME AND ABROAD

THORNTON DAVIS, formerly district geologist for Simms Oil Company, has entered the consulting business at San Antonio, Texas.

FLOYD MILLER, geologist for the Bay Oil Company, formerly of Tulsa, Oklahoma, is now located in Houston, Texas, with headquarters in the Esperson Building.

ERIC A. RUDD, formerly of 1673 Cambridge Street, Cambridge, Massachusetts, may now be addressed in care of Oil Search Limited, 350 George Street, Sydney, New South Wales, Australia.

WILLIAM NORVAL BALLARD, geologist with the Phillips Petroleum Company, and formerly located at Oklahoma City, is now in the office at Bartlesville, Oklahoma.

RAYMOND J. STIPEK, formerly geologist for the Gulf Production Company, has received the degree of Bachelor of Laws and has been admitted to practice before the Courts of the State of Kansas and the Federal District Court.

J. L. TATUM, consulting geologist of McAllen, Texas, has a paper in *The Oil Weekly*, issue of June 10, entitled "Geology and Exploration in Northeastern Mexico."

DILWORTH S. HAGER, geologist and operator, has closed his San Antonio offices and moved to Dallas, to be near his operations in the Red River district.

WILLIAM V. HOYT, independent geologist, has moved his office from Houston to 805 West Thirteenth Street, Cisco, Texas, and will devote time to production from shallow sands of Cisco and Strawn formations of north central Texas.

F. G. TICKELL, formerly of Palo Alto, may be addressed in care of the Department of Mining Engineering, Stanford University, California.

FOLKE H. KIHLSTEDT has become consulting mining engineer for the Atlantic, Gulf and Pacific Company, Manila, P. I.

SIDNEY PAIGE, geologist, has returned to the United States from Turkey, where for the past two years he has served as adviser on geology and mineral resources to the Government. He will resume consulting practice with headquarters in Washington, D. C.

L. E. PATTERSON has changed his address from Larned, Kansas, to 918 Milam Building, San Antonio, Texas.

CHARLES N. GOULD spoke before a luncheon meeting of the Oklahoma City Geological Society, June 24, on "The Pioneers of Oklahoma Geology."

FRANK T. CLARK, geologist with the Empire Gas and Fuel Company, and formerly located at Bartlesville, Oklahoma, is now with the same company at Midland, Texas.

W. C. HOWELLS, with the petroleum and natural gas division of the Alberta Lands and Mines Department at Edmonton, is spending the summer in charge of a federal geological survey party in the Foremost area of southern Alberta.

F. S. PROUT has moved from Tyler, Texas, to Bartlesville, Oklahoma. His address is Box 395.

LYNN W. STORM, geologist with the Sun Oil Company, gave an illustrated talk before the Houston Geological Society on the evening of June 27, at the auditorium of the Houston Public Library, and discussed the national parks of the Southwest and of Alaska.

L. KEHRER, who has been in Olten, Switzerland, is again located at Caracas, Venezuela, with the Caribbean Petroleum Company.

L. S. RUSSELL, of the Geological Survey at Ottawa, Ontario, Canada, has established headquarters at Foremost, Alberta, for a survey of oil and gas possibilities in the southern part of the province. The work will continue until October.

LUTHER H. WHITE, geologist with J. A. Hull Company, has been appointed to the Tulsa County excise board.

F. C. WOOD, consulting geologist and mining engineer of Denver, Colorado, has been appointed assistant to ROBERT H. DOTT, newly appointed director of the Oklahoma Geological Survey.

J. M. WILSON, formerly chief geologist for Simms Oil Company, Dallas, has moved to San Antonio, Texas, and will be chief geologist for the newly organized Texla Oil Company.

The Kansas Geological Society (Wichita, Kansas) holds its Ninth Annual Field Conference this month, beginning at Iowa City, Iowa, August 25, and ending at Duluth, Minnesota, September 1. It is held in coöperation with the State Geological Surveys of Iowa, Illinois, Wisconsin, and Minnesota. A guide book of 300–400 lithographed pages, including comprehensive statements of the geology of the area, maps, sections, road logs, et cetera, is available for those who attend and those who may prefer to follow the same itinerary later. For prices and other information, write ANTHONY FOLGER, chairman of the committee on arrangements, Gypsy Oil Company, 1107 Union National Bank Building, Wichita, Kansas.